RAYS

Visible and Invisible

By FRED REINFELD

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With the eyes of the world watching for new scientific achievements and the nation searching the schools and colleges for science-minded students, this book fulfills the vital task of helping you learn all that is known about rays.

Presenting material from leading scientific sources, it is aimed directly at the person who wants to know the facts about radiation, radar, electronics, television, nuclear activity, solar rays, gamma rays, cosmic rays and all the other rays and waves, and wants these mysterious subjects explained in clear, simple language, with show-how photographs and drawings.

All the excitement of these complex subjects is maintained by the author throughout the easy-to-follow, step-by-step explanations.

"You cannot have good science without having good science fans. Today science fans are people who are only interested in the results of science. They are not interested in a good play in science as a football fan is interested in a good play in football. We are not going to be able to have an excellent scientific effort unless the man in the street appreciates science."

EDWARD TELLER,
leading atomic scientist

The jacket photo, a self-portrait of a nuclear reactor in operation, was taken by radiation at Oak Ridge National Laboratory. Courtesy, Union Carbide Corporation.

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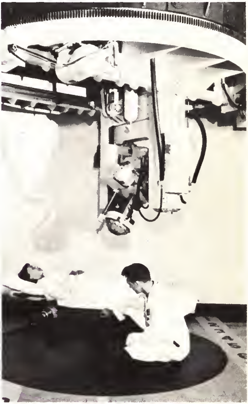

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MIRACLE DRUGS AND THE NEW AGE OF MEDICINE

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The Los Angeles Harbor lighthouse operates with a flashing light powered by a solar converter panel which is capable of developing up to 20 watts of electrical power from the sun's rays. Containing some 400 silicon cells, this device converts about 10 per cent of received sunshine into electrical energy. To achieve maximum efficiency, it is equipped with an automatic tracking element to follow the sun across the sky. This solar converter operates for at least six months without requiring any attention.

1. The Sun's Energy

Thousands of years ago, long before the age of science began, men instinctively recognized that life on earth was dependent on the sun. Primitive peoples everywhere had their myths and legends about the great ball of fire in the sky. Sun-worship was widespread — in ancient Babylon, Egypt, Greece, and the Roman Empire, and among the North American Indians, the Mayans, and the Incas as well.

VITAL IMPORTANCE OF THE SUN

Science has since confirmed the life-giving properties of the sun. All the latest theories of the origin of life on the earth establish the sun as one of the essentials.

The conditions under which we live today seem just right. If the sun's radiation were to decrease 13 per cent, a mile-thick layer of ice would cover the whole surface of the earth. A 30 per cent increase in the sun's radiation, on the other hand, would destroy all life.

Plants get their energy from sunlight. Without that energy all life would be impossible on earth, for plants are the ultimate source of human and animal energy.

Sunlight and its direction also determine our changes of season. When the sun breaks up each twenty-four hours into day and night, it controls our living habits and most of our activities. Our health and ability to see are dependent on the sun.

Coal, a vitally important fuel, is actually the fossilized remains of plants that have been dead for millions of years. The energy we get from coal was originally stored in these plants by the action of sunlight. This energy can be transformed in various ways until sometimes we lose sight of the fact that it came from the sun.

For example, coal is burned to yield a different form of energy: heat. By applying the heat to water, we get steam to power steam engines which run dynamos (mechanical energy). The dynamos generate electricity (still another form of energy), which we employ in countless useful ways.

OUR CHANGING CLIMATE

The earth's climate, which is controlled by the sun, has undergone vast changes, some of them catastrophic. There have been four, perhaps five, great ice ages at intervals of 250,000,000 years, each lasting several million years. During the intervals the earth has had a comparatively warm climate.

The last ice age ended about 20,000 years ago and the earth is now in a warming-up period. Both the North and South Poles had a tropical climate at one time or another. The ice sheet which still covers Greenland is slowly receding; there is indisputable evidence that fig trees and hundreds of other tropical plants once grew there.

All over the world, in a state of warming climate, temperatures are creeping up, and soon the human race will be confronted with many troublesome problems. With more and more of the polar icecap melting, the level of the oceans will rise, menacing the existence of great coastal cities. The encroachment of salt water onto land will decrease sources of fresh water. (For some of the ways that science has already tackled the problem of converting salt water to fresh water, see pages 26 and 164.) With tropical climate reaching up into the temperate zones, air conditioning will become a universal neeessity.

Already some meteorologists have suggested that blowing huge plastic bubbles across the sky might be a feasible method of minimizing the effects of too much sunshine. And doubtless even more ingenious techniques will be devised in the course of time. One cheering feature of the heating-up is that something like a third of the earth's surface which is now wasteland will be warmed up enough to become habitable and productive.

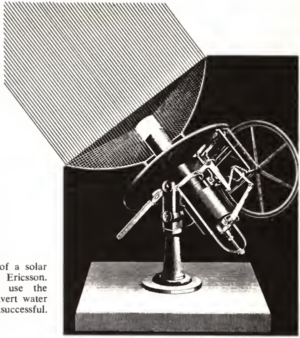
INSIDE THE SUN

The study of our star, the sun, in all its aspects is one of the most intricate and fascinating problems in the whole range of science. Much has been learned about it; much still remains to be learned.

The volume of the sun is more than a million times greater than that of the earth. Despite its distance of 93,000,000 miles from us, the sun's gravitational pull keeps our small planet (and all the other planets) in orbit. There are many larger stars than the sun, but of course they are more distant and appear smaller in our sky.

The sun is an incandescent globe of gases heated to fantastic temperatures — 6,000 degrees Centigrade* at its outer rim, which is of

* To convert a Centigrade reading to Fahrenheit, multiply the Centigrade figure by 9/5 and add 32°.



An early model of a solar engine by John Ericsson. His attempt to use the sun's rays to convert water into steam was unsuccessful.

course the coolest part. The inner temperature is counted in millions of degrees. (Some other stars are believed to have much higher temperatures.)

By studying the wave-lengths of solar radiation (page 32), astrophysicists have found that 66 elements present on earth are also found in the sun. Practically all of these elements occur in about the same proportions as on the earth. There are two exceptions — hydrogen and helium, which are extraordinarily plentiful in the sun.

Under the sun's terrific temperatures hydrogen atoms are fused and converted into helium, turning the sun into a huge atomic furnace that gives off enormous quantities of energy. (This fusion process, which takes millions of years in the sun, has been reproduced by man in the H-bomb, where fusion takes place in less than a millionth of a second.) Astrophysicists believe that it will take a billion years for just 1 per cent of the sun's hydrogen to be converted into helium.

Most of the matter in the sun is atomic, or sub-atomic; there is very little molecular matter because of the intense heat. One result

is that there are inconceivably huge amounts of free electrons — negatively charged atomic particles.

SUN-SPOTS

The pressures at the sun's core are on the order of one billion tons to the square inch. These terrific pressures lead to expansion and release of energy, which in turn results in cooling and contraction. The pressures build up again, and the cycle of expansion and contraction renews itself.

The expansion also results in release of some of the closely packed gases which are forced to the surface and away from the sun. According to one theory, the emergence of these densely packed gases is responsible for "sun-spots." Scientists have known for more than a century that sun-spots go through cycles of gradually increasing, and then waning, intensity. Each of these cycles takes about eleven years to run its course.

Some of the effects attributed to sun-spots are just folklore. Nevertheless, sun-spots do have important results. The sun's radiation (emission of energy) is most intense when the cycle is at its high point. Consequently, at such times water is evaporated more rapidly from oceans, seas and rivers. Melting of glaciers speeds up; more ice drops off from the polar icecaps. In some regions, rainfall increases. Additional radiation also means larger crops and a rise in the animal population that feeds on the increased vegetation. The effect of sun-spots on radio waves (page 92) has received a great deal of study.

Sun-spots come in widely differing sizes. One that was observed in 1944 had an area of 6,000,000,000 square miles. Others may have a width of only several hundred miles.

Another remarkable feature of the sun is the corona, a halo which is comparatively dim; it can be seen only when the sun is in eclipse. Scientists believe the temperature here is 1,000,000 degrees Centigrade, and some think that the corona is made up of free electrons darting about at incredible speeds. Observations made during the 1954 eclipse showed that the corona extends for some 2,000,000 miles beyond the sun.

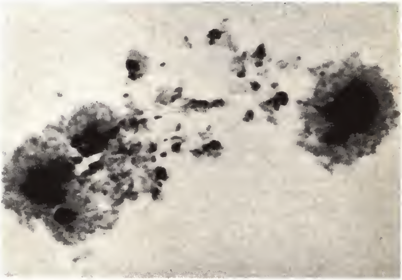
ELECTROMAGNETIC RADIATION

It is believed that the sun has been sending out its present amount of light energy for at least a billion years — perhaps two billion years. According to scientific calculations, every 564,000,000 tons of hydrogen is converted into 560,000,000 tons of helium; the difference is released energy.

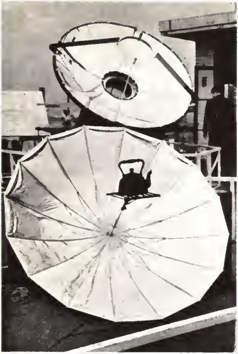
According to the theory of James Clerk Maxwell, the great nineteenth-century physicist, light is one of the forms of electromagnetic radiation. All these forms travel at the same speed as light — a little over 186,000 miles per second.

Of all these different forms (listed on page 28), only one kind is visible — what we call "visible light." (Strictly speaking, we do not see "visible light" — we see its source and any objects that are reflected to our eyes by "visible light.")

All forms of electromagnetic radiation move in a series of vibrations, forming a succession of waves. Each type of radiation has a different range of wave-length — this being the distance from the crest of one wave to the crest of the next wave. Thus, the wave length of gamma rays has an upper and lower limit. All rays inside this range are gamma rays. But ultraviolet rays have a totally different wave length. Other types of radiation have still other wave lengths. The differences from one group to another have made it possible to devise instruments which identify the kind of radiation that is detected.



Observations of astronomers indicate that changes in the intensity of sun-spots are related to changes in the intensity of the sun's radiation. The changes take place in cycles about eleven years long.



Two types of reflecting mirrors for cooking are shown here. In front is an "open-parasol" reflector coated with an aluminum-plated plastic. The stem which supports the stand for the cooking vessel can be adjusted to keep the sun's rays in focus. In the rear, the convex auxiliary reflector directs solar heat to the main parabolic reflector. Light is reflected through the center opening to an insulated box that contains the cooking vessel.

The number of waves that any kind of radiation creates in a second is called its "frequency." (To find the frequency, we divide 186,000 by the wave-length.) It follows, then, that radiation with a long wave length has a low frequency, while radiation with a short wave-length has a high frequency. The shorter the wave-length, the higher the frequency; the longer the wave-length, the lower the frequency.

What determines wave-lengths ? The amount of energy carried by the radiation. High-energy radiation has short wave lengths and high frequency. Low-energy radiation has long wave lengths and low frequency. As you will see in the next chapter, all the different kinds of electromagnetic radiation can be arranged in a graduated series of bands from the highest frequency to the lowest. This arrangement is called a "spectrum."

Some of the sun's radiation — for example, gamma rays and ultraviolet rays — would be deadly if it reached us with all its original energy. But in the course of their travels, the rays collide with other particles and lose some of their energy each time, being converted

into rays with longer wave-lengths. In addition, once they reach the earth's atmosphere, they lose so much more of their energy that they reach the earth in a harmless form. Thus we owe our lives to the protection afforded us by the earth's atmosphere.

WHAT IS ENERGY?

The problem of utilizing the sun's radiation to produce energy is being worked on vigorously in many parts of the world — not only in the most advanced areas but in some of the most backward ones. To appreciate the importance of these efforts, it is necessary to know something about the nature of energy.

Energy is the capacity or ability to do work. There are various forms of it, and one form can be converted into another form by appropriate techniques. Kinetic energy, for example, is produced by motion (another form of energy). Thus, when water from a dam or waterfall turns the blades of a turbine connected with a generator this produces electricity, also a form of energy.

Potential energy is energy that is stored up for future use. Food contains potential energy. After food has been eaten, some of it goes to the muscles of the body. When the muscles move, we have an example of potential energy being converted into kinetic energy to produce motion.

Light, heat and sound are some of the other forms of energy.

THE NEED FOR ENERGY

When Abraham Lincoln was a boy, he did his homework at night on the floor, making use of the dim light that came from the fireplace. This is a homely example of the meager consumption of energy that was characteristic of earlier, more easygoing times.

With the development of scientific discovery and the coming of the Industrial Revolution, a shattering change took place. In the last two centuries, the per-capita consumption of energy increased two-thousandfold. In fact, it has been estimated that of all the energy used by man in the last two thousand years, fully half was consumed in the years 1850–1950.

Our modern world, with its myriad activities, processes and products, would be unthinkable without huge amounts of energy and innumerable methods of employing it. We need coal, oil, electricity and other sources of energy to provide heat, lighting, fuel for our homes and factories, and to power our plants, vehicles and appliances.

When electric power is cut off temporarily during a storm, we get a vivid idea of what the world would be like if our usual sources

of energy were to be exhausted. The momentary lack of electricity is, to be sure, a comparatively small inconvenience. But the danger that some day all our present sources of power will be used up is a very real one. This is especially so because the rate of consumption increases all the time. An added difficulty is that our fuel sources of energy are not fully efficient. They are costly to produce and transport and store. And there is an even more frightening problem: the world's population is increasing very rapidly, its food supply very slowly.

USING SOLAR ENERGY

For all these reasons, more and more scientists have been turning to the problem of how to use the sun's radiation as a source of energy. Theoretically, this is an ideal source. In the course of a year, the radiation from the sun adds up to a million trillion kilowatt hours — and it is all free!

In a mere 24 hours the land areas of the earth, which comprise less than half its surface, receive more energy from the sun than man has utilized from all other sources during his whole existence. Theoretically, then, sunlight is an ideal and cheap source of energy. The amount of heat we get from the sun is so enormous that if our conventional sources of energy had to produce heat at the same rate, the world's whole present supply of energy would vanish in three days. If all our sources of atomic fuel were utilized at the same rate, they would be exhausted in an hour.

Using solar energy becomes even more inviting when we realize that all but a tiny proportion of solar radiation is now being wasted. The earth's atmosphere filters off more than half of this radiation. Of the part that reaches the earth, a great deal is wasted on the oceans and polar regions. Practically speaking, the only useful consumption of sunlight is in photosynthesis, a process which plants carry on to make their own food. But this amounts to 1/2,000th of the available radiation. All the rest is lost!

What makes the idea of using solar energy so attractive is that in effect all our engines are really solar engines. They use fuel (such as coal, oil or water power), which originated at some time or other from solar radiation. A plant is a solar engine, since it gets its energy from the sun. Even a cow is a kind of solar engine, since it gets its energy from plants which are the products of photosynthesis. So why not get this energy right from the source? It is when we turn to methods of obtaining solar energy that we find forbidding difficulties. Solar radiation is free, but most of the methods of utilizing it are at present discouragingly expensive.

The trouble is that the solar heat collectors (mostly mirrors) which have been designed so far are comparatively inefficient in focussing the sun's light rays. Consequently, huge equipment is often required in order to yield a rather small amount of usable energy. Mirror equipment is expensive, and so is land. (On the average, it requires seven feet of land to be able to generate one horsepower.) To insulate equipment so that heat gathered in the daytime is not dissipated during the night, is an additional cost factor.

Large-size mirrors are necessary, too, because the amount of heat collected increases in square ratio. Thus, if one mirror has a 9-foot diameter and another mirror a 27-foot diameter, the increase in heat is not threefold but ninefold.

Another problem is geographical location: solar collectors have to be in areas that enjoy a great deal of sunshine. Above all, solar

A portable solar cooker developed at New York University by Dr. Maria Telkes. The sun's rays are reflected to focus enough heat radiation for cooking food.

energy has thus far suffered from a paradox: highly industrialized regions don't need it because they have cheaper and more efficient sources of energy; backward regions, which need it most, lack the funds for extensive development.

Nevertheless, some of the finest scientific minds of our time are devoting intensive research to the problem. The search for cost reduction and heightened efficiency is yielding some highly ingenious solutions.

PAST ATTEMPTS

The knowledge that solar energy can be put to use goes back to ancient times. According to some accounts, the most remarkable application is credited to Archimedes, considered the greatest of the ancient Greek scientists.

In 212 B.C., when Archimedes was a very old man, his native Syracuse in Sicily was attacked by a Roman fleet. According to old Byzantine manuscripts, Archimedes destroyed the Roman fleet by placing a number of mirrors in a spot where they focussed light rays on the enemy galleys and set them on fire. In the twelfth century A.D., the Byzantines are said to have destroyed an invading fleet in the same way.

In the seventeenth and eighteenth centuries, solar heat was concentrated by large lenses to break down diamonds and metals in the course of scientific experiments. In those days no other form of heat was available for the purpose.

In 1747 Buffon, the famous French scientist, conducted some experiments to test whether the feat attributed to Archimedes was really possible. Buffon found that by setting up a combination of flat mirrors he could burn wood at a distance of 200 feet and melt lead and silver at lesser distances.

About forty years later, another great French scientist, Antoine Lavoisier, constructed a solar furnace during his experiments to disprove an old theory of the cause of combustion. He nearly succeeded in melting platinum, so it is thought that he must have obtained temperatures of over 1,700 degrees with his solar furnace.

Captain John Ericsson, best remembered for designing and constructing the *Monitor* during the Civil War, was strongly interested in solar energy. As he put it, he wanted to know more about "the intensity of the big fire which is hot enough to work engines at a distance of 90,000,000 miles."

After some theoretical studies of the sun's production of energy, he built a number of "sun-motors." Ericsson's objective was to con-

vert water into steam through the action of the sun. He understood the theoretical possibilities very well, remarking that "the field awaiting the solar engine is almost beyond computation, while the source of its power is boundless."

However, Ericsson never solved the practical difficulties. Dissatisfied with the comparative inefficiency of his engine, he converted it to run on coal or gas and made a fortune from this device.

MODERN PROJECTS: SOLAR HEATING

More fuel is consumed in home heating than any other way. In the United States, home heaters use three times as much fuel as railroads; or twice as much as all cars, trucks, and planes; and in fact, more than the total needed for all manufacturing and mining operations. What makes these comparisons even more remarkable is that space heating calls for relatively low temperatures.

So it is fair to conclude that a substantial proportion of the 500,000,000 tons of coal annually consumed in the United States could be saved if we had a more efficient home solar heating method.

Solar heating is not dependent on transportation or on a central power source. Heating water from solar heat collectors is already well advanced and quite practical in regions that enjoy ample sunshine. Here is the principle on which a heat collector works:

The rays of the sun are made up roughly of 80 per cent visible light, 16 per cent infrared rays and 4 per cent ultraviolet rays. The infrared rays are what we need for heat. These have fairly short wave lengths and pass readily through glass. Once these rays have penetrated the glass of the heat collector, they strike objects that are dark and solid and are transformed into long-wave rays. Such rays have little ability to pass through glass, so that most of them are trapped. As more and more heat remains inside, the room becomes warm. (This principle has been applied for centuries in greenhouses to supply extra heat to plants for rapid and healthy growth.)

Roof reflectors collect the solar heat during the daytime — more heat than is needed for the daylight hours. The surplus heat is stored by various methods and controlled to any desired level by a thermostat. Later, when the sun goes down, the surplus heat can be released.

In places where there is a great deal of sunshine, such as in tropical climates, south-slanting roofs collect and store heat which is led to special plumbing systems. In this way it is possible to supply all the household heat without recourse to any conventional fuel. Where the roof is unsuitable — if it does not slant south, for example — it is still possible to use certain types of heat collectors.

Some remarkably ingenious ways have been found for solar heating in areas that have only a moderate amount of sunshine. A pioneering effort in this direction was a house built at Dover, Massachusetts, in 1948 which obtained 95 per cent of its heat from the sun. This house stored surplus heat in containers of Glauber's salt which retained the heat until it was needed.

A later house built at Denver, Colorado, in 1957 stores heat in drums containing chunks of granite. Once the rocks have been heated sufficiently, they can hold enough warmth to supply the needs of the house for four overcast days.

SOLAR WATER HEATER

Similar methods are employed to get hot water. A shallow box, preferably of blackened sheet metal, is fastened to the roof or heat collector. Every 1½ square feet of surface will yield a gallon of hot water. The pipes of the hot-water system (or thin, flat tanks) are placed in the bottom of the box, which is thoroughly insulated and covered with glass.

When cold water enters the collector, it passes through the pipes, gets heated and passes back to a boiler. Then more cold water is supplied, and so the process is continued.

The upkeep of such a system is not cheap, but the total expense involved is less than in the case of our regular fuels. However, there is no doubt that the heat collectors now available need to undergo a great deal of improvement before they can pass into common use.

Solar heating equipment can be adapted to operate refrigerating and air-conditioning units quite efficiently. Several systems have already been devised for these purposes.

SOLAR FURNACES AND BOILERS

It has been known for a long time that large, curved, outdoor mirrors can be used to concentrate solar heat to create extraordinary temperatures — in some cases, it is said, to 8,000 degrees Fahrenheit.

In 1932 a solar furnace was built at the California Institute of Technology to study the effects of high temperatures. It uses nineteen lenses, each of which has a two-foot diameter; and temperatures of 3,500 degrees Centigrade have been attained.

Here it is possible to study the effects of high temperatures on guided missiles, for, moving at speeds of 4,000 miles per hour they reach temperatures which present serious technical problems. Designers of high-speed airplanes have to contend with the same kind of problems — those involving the melting of metals at high tempera-

A front view of the great solar furnace at Mount-Louis in the French Pyrenees. The parabolic mirror, the largest of its kind in the world, contains 3,500 lozenge-shaped panes of glass 1/16th of an inch thick.

tures. These furnaces also offer the best method known for purifying metals to an exceptional degree.

A solar furnace 26 feet in diameter does a remarkable job in Algeria. It "fixes" nitrogen from the atmosphere, supplying the soil with fertilizer, thus increasing crops appreciably.

Experimentation with steam engines powered by solar heat has been going on for a century. In the past, such engines proved impracticable because they were too expensive; because they were comparatively inefficient; and because they could operate only when sunlight was available.

However, in recent years more substantial progress has been made. The biggest solar furnace and research laboratory is located at Mount-Louis in the French Pyrenees. It has the largest parabolic mirror in the world, made up of 3,500 lozenge-shaped panes of window glass 1/16th of an inch thick. These had to be shaped with the utmost care to fit perfectly in place.

Eighty feet away is a second mirror. This one is flat, with an area of 460 square feet and containing 560 individual mirrors. It catches sunlight and directs the rays toward the parabolic mirror, which in turn focusses the rays into the opening of the solar furnace placed between the two mirrors.

No human action is needed for this. A pane on the flat mirror directs an image of the sun to a group of photoelectric cells. When light waves strike any photoelectric cell, they knock out huge numbers of electrons. This creates an electrical current — which is nothing but a flow of electrons. Though the current may be feeble, it is adequate to cause a small switch to activate a mechanism which, for example, will open a door.

In the case of the solar furnace, every time the position of the sun changes, the position of the image changes accordingly. Every such move causes the photoelectric cells to send an electronic message to pistons which move the mirror to adjust its position with respect to the sun's new position.

The furnace, which can produce temperatures up to 5,400 degrees, is used thirty days a year to produce high-resistance metals in an extremely pure state. During the rest of the year the scientists at the station carry on valuable research into the nature and application of solar energy.

One of the most interesting projects at solar laboratories of this kind is tackling the problem of devising a suitable fuel for spaceships. One method is to use a reflecting mirror to focus the sun's rays to heat a boiler for making steam. Another method that has been sug-

gested is to use the same technique to heat liquid mercury into a vapor which drives a turbogenerator with a capacity of 500 watts. As the vapor comes off, it is cooled and condensed back into liquid form, and is thus constantly self-renewing.

The Russians have announced the building of the first commercial solar-power station, with some remarkable features. The site, selected because it receives an exceptionally large number of sun-hours throughout the year, is located in Soviet Armenia.

Large mirrors will capture the sun's rays to heat a boiler which will relay steam to a turbine of 1,200-watt capacity. To follow the angle of the sun, the tower containing the boiler will be surrounded by 23 circles of steel track. On each track there will be a train automatically directed by 1,300 large mirrors placed on the train "stations." As the rays are received, they will act on photoelectric cells which will keep the machinery turning the mirrors in accordance with the position of the sun.

This arrangement will be synchronized with another automatic process for focussing the direct rays of the sun onto the flat surface of the boiler. It is expected that the station's annual output will amount to 2,500,000 kilowatt-hours of electricity.

The station has several subsidiary purposes. For example, the solar energy can be used to pump water out of nearby swamps and transport it to nearby deserts in another direction. Both types of wasteland can be simultaneously reclaimed. Even the exhaust steam will be used—to make ice for farms in the area. Underground quarters will store unused heat, which can be drawn upon at night and on overcast days.

The Russians claim to have other solar-energy projects under way. One of these is a "sun-kitchen suitcase," a transportable solar cooker which operates on simple and highly convenient lines.

The motif that runs through all research on solar energy is the striving to increase the efficiency of all solar devices. In 1955 Harry Tabor, director of Israel's National Physical Laboratory, devised a novel method of making solar energy more efficient. The basic design for a solar-energy collector requires the use of a blackened metal plate. However, any black object is a strong radiator of heat. Tabor ingeniously prepared a surface that "looked" black, yet was not black from the point of view of physics. The result is that it absorbs a great deal of sunshine but loses very little heat. Consequently his plate become much hotter than conventional plates.

Tabor's plate radiates its heat when placed in contact with water pipes. His discovery, Tabor says, makes it possible to turn 16 per cent of the solar energy received to power uses. This is a high percentage.

SOLAR COOKERS

In some parts of Mexico, women have to walk six miles to gather twigs and firewood for their cooking. Under such conditions the advantages of solar cooking are obvious; for it is free, readily available, clean, requires no fuel, and leaves no ashes or soot. Solar cookers are now being developed in many countries. A comparatively small circular reflector will bring water to a boil in ten minutes.

In India the two chief sources of fuel have been wood or dried cow dung. The first method cuts down the forests, the second reduces the supply of fertilizer. In either case land becomes less productive and crops are reduced, menacing the food supply. So solar cooking is an admirable solution to this dilemma. An effective solar stove can be mass produced at a cost of $5 or so.

This metal stove has hinged reflectors to gather the sun's rays, and, by utilizing cans containing Glauber's salt, stores gathered heat for use in cooking after the sun has gone down.

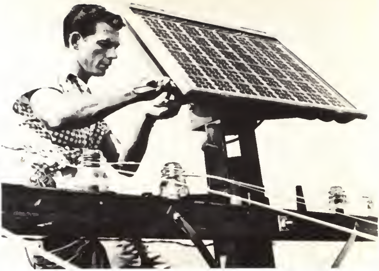
Other cheap solar stoves use reflectors which focus the sun's heat to a single spot that will get warm enough for cooking. In this type of stove it is necessary to make slight adjustments by hand from time to time to compensate for changes in the position of the sun. To help retain heat, the bottoms of the cooking utensils are blackened. Despite its simplicity, such a device will be immensely helpful in raising the standard of living in poverty-stricken countries.

DIRECT CONVERSION TO ELECTRICITY

For a long time it was considered necessary to make steam as an intermediate step in converting solar energy into electricity. Then scientists began to wonder whether it was possible to devise some way of having direct conversion, eliminating the intermediate step.

The first such approach involved the principle of thermocoupling. A thermocouple is a junction of two different metals which has the quality of setting up an electric current when it is heated. As in the case of the photoelectric cell, the amount of current is tiny but sufficient to perform small tasks, such as opening a door or ringing a bell.

A German scientist hit on the idea of using a number of thermocouples and heating them with the sun's rays to keep a lamp burning for several months. A French scientist has suggested connecting 500,000 thermocouples and exposing them to sunlight to obtain huge amounts of electricity. Whether or not this would work is not certain, but it would certainly be far more expensive at present than conventional ways of generating electricity.

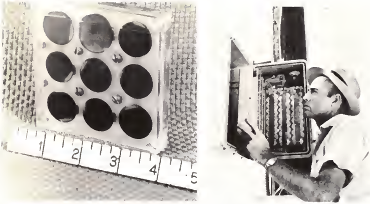


One of the earliest tests of the solar battery developed by the Bell Telephone Laboratories took place in 1955, when these batteries were installed to power transmission of regular telephone messages at Americus, Georgia.

The small and amazingly simple solar battery developed by the Bell Telephone Laboratories in 1954 is much more effective. Made of wafer-thin transistor disks of silicon which are extremely sensitive to light, it has been used to supply power for transmitting voices over telephone wires, for operating a transistor-radio transmitter in American satellites, and for keeping a solar clock going for a year.

The key to the operation of the battery is the precisely controlled introduction of tiny impurities into the silicon. The silicon requires special processing, but it is readily obtained from sand, which is one of the world's most plentiful materials. Silicon has other advantages: it has excellent stability under high temperatures; as there are no moving parts, the battery should last indefinitely; and a high degree of efficiency has been achieved — 11 per cent conversion of sunlight into electricity. This compares favorably with the best gasoline engines.

The solar battery has a great potential for further development. One point of departure is that silicon batteries can be linked together electrically to deliver power from the sun at the rate of 100 watts per



(Left) The solar battery, which contains nine silicon cells, is only three inches square. (Right) An advantageous feature of this solar battery is that excess current not needed immediately can be fed into a storage battery and become available at nighttime and when the weather is bad.

square yard of surface. As the battery is developed to deliver a stronger electrical output, it may very possibly be adapted for home heating and lighting, and for powering automobiles.

An even more novel method of using solar energy to obtain power is the production of hydrogen by using light-sensitive chemicals which, when exposed to sunlight, dissociate the hydrogen and oxygen that make up water.

One way to accomplish this is by the action of ultraviolet rays on chemical solutions. Another way is to use catalysts — substances that initiate chemical reactions without participating in them — which will decompose water when they receive energy from sunlight.

The advantages of this process are that the gases are easy to store; the collector required is simple and inexpensive. Also the products can be used with considerable efficiency in the hydrogen-oxygen fuel cells to produce electricity, as are now being developed in England.

INCREASING OUR FOOD SUPPLY

Most of the fuels which we convert into energy come originally from green plants. This is also true of our food, for meat comes from animals which in turn got their food from plant matter.

Of all living organisms, plants are the only ones that can convert non-living matter into living matter. This is done by the process of

photosynthesis. It can take place only where light (most generally sunlight) is available.

All green plants contain chlorophyll — green coloring matter. The presence of sunlight and chlorophyll breaks down carbon dioxide and water into oxygen and carbon and hydrogen. The three elements then combine into carbohydrates. These are starches, and some of them are recombined into fats and proteins. Thus, in effect, the sun's energy is converted into food substances that will be a source of energy.

Though this process is a marvelously efficient one, it is wasteful in the sense that plants use only a trifling portion of the energy that reaches them from the sun. It follows that we can increase our food supply enormously when we discover the secret of photosynthesis. If our scientists can create artificial photosynthesis, they will find more effective ways to consume the solar energy available for photosynthesis.

Two other factors greatly decrease the amount of food available to the world's population. One is that agriculture is far less efficient than it might be; the other is that almost half of all plants known are not suitable for food. All three difficulties can be solved, scientists believe, by the cultivation of algae. These are one-celled plants, the oldest and most primitive on earth. They can be grown anywhere, are fully edible and rich in food values.

Scientists are carrying on important experiments with algae to make their common use possible and economical. One fascinating feature of these experiments is that the most promising kind of algae, *Chlorella pyrenoidosa,* can be grown with controls that determine the proportions of carbohydrate and protein.

Dr. Sydney Greenfield of Rutgers University has suggested that chlorella would be the ideal food for travelers in spaceships. He points out that in dehydrated form it contains 50 per cent protein as well as valuable minerals and vitamins.

If scientists can master the photosynthesis technique, they can probably apply it to "growing" industrial fuels by utilizing sunlight. Some of them, for example, are using dyes which, like chlorophyll, are very sensitive to sunlight and might be capable of doing the same job — of creating chemicals that can obtain energy from the sun's rays.

Thus, when the proper dye is applied to iron salts and they are exposed to sunlight, a small amount of electrical current is generated because a flow of electrons is released. In effect, the iron salts have been converted into an electrical cell that can be used indefinitely.

INCREASING OUR WATER SUPPLY

During World War II a very ingenious device was developed to distill small quantities of sea water for fliers shot down over the sea. Attached to a life raft, this small device yielded about a quart of drinkable water in 24 hours.

Distilling water is the process of removing the salts from sea water in order to augment our fresh-water supply. Heating vaporizes the water while the salts are crystallized, resulting in the separation of water and salt. This is an extremely costly process when conventional fuels are used, so that a solar engine may turn out to be an economical solution.

It has also been suggested that a solar engine might be designed to drain water from below the surface of deserts and irrigate them, turning them into fertile lands.

THE FUTURE

These, then, are some of the ways in which scientists are working in the hope of some day harnessing the trillions of horsepower that are theoretically available from the sun's rays.

In 1955 the Rockefeller Foundation made a grant of $250,000 for a study of solar energy under the direction of Farrington Daniels, a leading authority in the field. Dr. Daniels takes a realistic view of the prospects for utilizing solar energy. He does not believe it can ever compete with nuclear power, but he does feel that solar energy can play an important role in replacing human and animal power which is still used to a considerable degree on farms.

Thus far the utilization of solar energy has generally proved too expensive. Dr. Daniels holds that important economies can be effected by replacing glass and metal with suitable, inexpensive plastics; and that, by 1975, 13,000,000 American homes will be heated by solar energy.

The project also covers such practical aspects as solar cookers, solar distillers (for distilling salt water), solar refrigerators, solar engines, solar air-conditioning, and solar irrigation pumps. Other facets of the study are devoted to theoretical aspects of solar energy, such as photosynthesis and photoelectricity (the conversion of light into electricity).

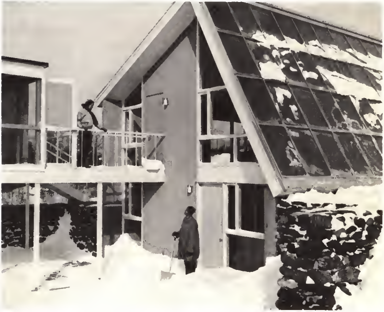
Developments in this field have come very slowly, but they will undoubtedly pick up speed as the urgency of the problem comes to be more generally realized. In 1951 the United States spent $2,000,000,000 on scientific research. Of this amount, only about $200,000 (or 1/100

of 1%) was spent on solar-energy research. Since that time the picture has slowly improved.

At present the trend is toward direct collection of sunlight, a comparatively inefficient and therefore expensive method. Some scientists believe that the most effective utilization of the sun's rays will eventually come from photochemical techniques.

A 1958 UNESCO report convincingly stressed the advantages of solar energy:

"In contrast to coal, oil, and uranium, which are limited in supply, the sun's energy is always recurring and inexhaustible. There are no restrictions on its use; no country can control the sunshine received by a neighboring country. There are no health hazards, no radioactivity, and no objectionable smoke or fumes."



This solar house was constructed at Lexington, Massachusetts, by a team of engineers and architects from Massachusetts Institute of Technology. It is the first modern house designed with a heat collector (see glass at upper right) in a northern climate.

2. The Wonderful World of Visible Light

About 450 years ago Leonardo da Vinci, the most versatile genius of the Renaissance, discovered the phenomenon on which all study of light is based. What he observed seemed so wonderful that he was afraid to publish his discovery lest he be condemned as a "sorcerer." So, instead of telling anyone about it, he wrote a description in one of the secret notebooks which he kept in mirror-writing. His discovery was lost to the world.

Another 160 years or so passed before another great scientific genius, Isaac Newton, made the same discovery and gave it to the world: he found that when sunlight is passed through a prism, it breaks up into its component colors.

ELECTROMAGNETIC RADIATION

Centuries later, it was found that visible light rays were a form of electromagnetic radiation. Today we know of many other kinds of electromagnetic radiation, but all these other kinds are *invisible*. Here is a list of different kinds of rays, starting with those of the longest wave-length and descending to those of the shortest wave-length:

long electric waves
long radio waves
standard radio broadcast band
short radio waves
television and radar bands
infrared (heat) rays
visible rays
ultraviolet rays
X-rays
gamma rays
cosmic rays

Long electric waves may have lengths of as much as 10,000,000 inches (approximately 160 miles), while cosmic rays (at the other extreme) have wave-lengths of .000000000000005 inches.

The standard broadcast band of wave-lengths runs from lengths of 21,500 inches to 8,000 inches.

The band of visible light rays lies between infrared rays (with wave-lengths of about .00003 inches) and ultraviolet rays (with wave-lengths of about .0000016 inches).

Inside the band of visible light rays there is a range of wave-lengths which our eyes register as color. Each wave-length has its characteristic color.

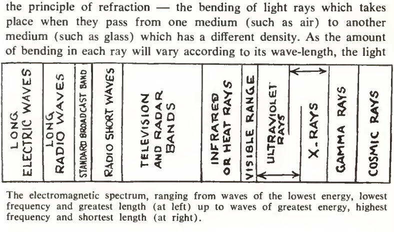
PRISM AND SPECTRUM

Up to the time that Isaac Newton performed his famous experiment in 1666, it was assumed that light was "white." To learn more about this, Newton darkened a room and bored a hole in a window shutter and placed a prism (a piece of glass with a three-sided cross-section) in it.

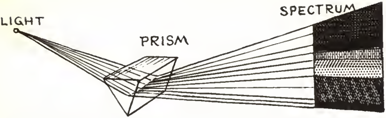
As the sunlight streamed through the prism, a band of vari-colored light appeared on the facing wall. Such a band of violet, indigo, blue, green, yellow, orange, and red is called a "visible color spectrum." Thus Newton demonstrated that the light which appears white to us is actually a blend of seven colors.

Later on, Newton also showed that the seven colors of the spectrum could be recombined into white light. This confirmed the result of his first experiment.

By forcing the light rays through the prism, Newton had illustrated the principle of refraction — the bending of light rays which takes place when they pass from one medium (such as air) to another medium (such as glass) which has a different density. As the amount of bending in each ray will vary according to its wave-length, the light



The electromagnetic spectrum, ranging from waves of the lowest energy, lowest frequency and greatest length (at left) up to waves of greatest energy, highest frequency and shortest length (at right).



The prism, pictured here, is one of the basic devices employed to study light and its effects. It is used in some valuable scientific instruments, such as the spectroscope.

is "dispersed" in the prism, and breaks up into the colors which are characteristic of the different wave-lengths.

A rainbow is a kind of spectrum. It appears in the part of the sky which is opposite to the sun. When you face the rainbow your back is to the sun. Rays of sunlight strike droplets of rain in the sky. This causes them to be bent and reflected (forced to bounce off). As the rays are bent in varying degrees, the natural (white) sunlight breaks into the colors of the spectrum, which are reflected back to the observer.

Since the appearance of the colors in the rainbow is due to the same phenomenon as their appearance in the prism, the order of the colors in the rainbow is the same as their order in the spectrum. What is represented is a graduated series of wave-lengths.

WHAT IS LIGHT?

Light, said Newton, is composed of tiny particles which he called "corpuscles." On the other hand, Christian Huygens, a Dutch scientist who was Newton's contemporary, maintained that light consists of waves. Both men had their partisans, but the "corpuscular" theory was widely accepted until 1801, when Thomas Young demonstrated that light rays travel in waves, and that the length of the wave determines the color.

The diffraction of light rays is another indication of the wave character of light. Diffraction is the term used for the apparent bending of light when it meets with an obstacle or passes through or near a small opening.

But toward the beginning of the twentieth century, the wave theory began to run into difficulties. Scientists had been fond of describing light as a stream of energy that flowed from its source like streams of water. But this could not account for mounting evidence that light sometimes seemed to be made up of particles.

Max Planck, one of the greatest physicists of the twentieth century, contributed his famous "quantum theory" to the dispute. According

to Planck, heated objects release light in tiny, distinct particles which he called "quanta." (The term "photons" is often used interchangeably with "quanta.")

When the temperature of the object is fairly low, the quanta emitted will have little energy and will be in the red, rather low-frequency stage of the spectrum (long wave-lengths). As the object heats up, the photons change progressively through the ranges of colors characteristic of higher and higher frequencies (shorter wave-lengths).

According to Planck's theory, the amount of light determines the *number* of quanta emitted; the wave-length determines the *size* of the quanta. Physicists have calculated that a candle gives off a million million quanta in a single second. (For a statement of the theory in terms of what happens in the atom, see page 132.)

Today scientists accept both the wave theory and the quantum theory of light. They use whichever one best explains a specific event in nature.

THE SPEED OF LIGHT

This is the fastest of all speeds. It is used in many kinds of scientific calculations, and it is therefore important to scientists to have an accurate measurement of this speed. Albert A. Michelson established shortly after the turn of the twentieth century that light travels at a speed of a little more than 186,000 miles per second. (The exact figure given by him has been slightly modified in later experiments.)

However, as early as 1675, astronomers had had a reasonable approximation of the speed of light. This was worked out by Olaus Roemer, a Danish scientist, while observing the time taken by one of the planet Jupiter's satellite moons to enter the shadow of Jupiter under various conditions.

Roemer found that this took 22 minutes more when the earth was furthest away from Jupiter than it took when the earth was nearest to Jupiter. He deduced that this was the length of time it took light to travel the length of the diameter of the earth's orbit of the sun. His calculations gave him a figure of 192,000 miles per second as the speed of light—an error of 3 per cent. (His initial figure of 22 minutes as the maximum interval was incorrect.)

The speed of light offers a convenient yardstick for conveying distances in space. These are so vast that when expressed in conventional figures it is impossible for the human brain to take them in. This led scientists to establish the distance-unit of the "light-year."

To arrive at this figure (the distance travelled by light in a year),

multiply 186,000 miles by the number of seconds in a year. This comes to about 6,000,000,000,000 miles a year. So, instead of saying that the distance between two stars is 6,000,000,000,000 miles, we say it is one light-year.

The ingenious utilization of light rays is the key to some of the most effective instruments ever designed by man. These include the spectroscope and the diffraction grating.

THE SPECTROSCOPE

In its most common form, the spectroscope is made up of three hollow tubes mounted horizontally on a disk which rests on a vertical shaft.

One tube has a slit (a few thousandths of an inch wide) at the further end and a lens at the nearer end. Light, made up of diverging rays, enters this slit and is formed into parallel rays by the lens (called a "collimating" lens).

Another tube serves as a telescope for observing the spectrum which will be formed by the light rays.

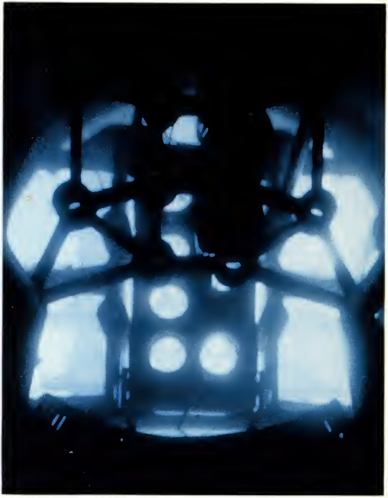
The remaining tube contains a scale which gets superimposed on the spectrum to provide accurate and convenient measurement.

At the center of the disk a prism bends the light which has entered the tube with the slit. This forms the spectrum which is viewed through the telescope.

Each chemical element, when it has been heated sufficiently, has its own characteristics and unvarying color and line-pattern on the spectrum. And so spectrum analysis is to the scientist what fingerprints are to the criminologist. For example, a certain pattern of yellow lines, in a definite relation to other lines, always indicates the presence of sodium. The sharpness of definition of the lines is determined by the amount of light that is focussed by the instrument.

With the use of a spectroscope it is possible to discover impurities in the proportion of one part in a million. (While such a proportion may seem trifling, it can make all the difference between success or failure in the case of transistors, nuclear reactor materials, and metals which have to withstand high temperatures.)

In the nineteenth century, when new elements were still being discovered, the spectroscope accounted for the discovery of ten elements, including germanium, indium, thallium, helium and cesium. One of these elements, helium, was discovered on the sun by spectroscopic methods before it was discovered on the earth; hence its name, from the Greek *helios*, meaning "sun." Helium is rarely found on earth, because it is an inert (chemically inactive) gas; in the sun, it is quite



Courtesy, Union Carbide Corporation

AN UNUSUAL PHOTO: This is a unique self-portrait of a nuclear reactor in operation at Oak Ridge National Laboratory. The eerie bluish glow emanating from the heart of the reactor is the radiation that would be visible to the naked eye.

A cut-away view of a spectroscope, showing the prism in the center which bends the light rays that have entered one of the tubes through a tiny slit. The bending of the light rays forms a spectrum which can be viewed through another tube which functions as a telescope. The third has a scale for measuring the spectrum.

plentiful, being formed by the transmutation of hydrogen by the fusion process.

In 1868, P. C. Janssen, while studying the solar spectrum in India during the sun's total eclipse in that year, came across some puzzling lines in the sun's spectrum. Another scientist, Sir Norman Lockyer, followed up these investigations in the same year and recognized the substance as a hitherto unknown element. He named it "helium" because it had first been detected in the solar spectrum.

Later on, W. F. Hillebrand obtained helium by pouring acid on uranium ore, but he did not realize that the product was helium. Finally in 1895 Sir William Ramsay, one of the great scientists of the day, announced the isolation of helium by the same process.

Helium is still rare, but some of it is obtained from the natural-gas

A model of a diamond as it rules grooves in a blank to produce diffraction gratings. The diamond has been enlarged 50 times, the grating 5,000 times.

fields of Texas and Arkansas, and the rest from uranium ores and some mineral waters.

As we know, the spectrum lines in the infrared and ultraviolet ranges are not visible, but they can be photographed. When scientists study such a photograph, the absence of the all-revealing color presents no difficulty to them; *for the length of the lines is proportionate to the wave-lengths* of the colors that were originally present. Thus, given the line lengths, the scientist knows what the original color must have been. And this in turn identifies the substance that is being investigated.

THE SPECTROGRAPH AND THE DIFFRACTION GRATING

The combination of a spectroscope and photographic equipment is known as a "spectrograph." Large spectrographs make use of an ingenious device known as a "diffraction grating."

You will recall that diffraction is the apparent bending of light when it passes through or near a small opening. In this case, the diffraction is caused by the slits of the grating. However, these slits are not empty spaces in a solid, as you would expect. Instead, the grating is made up of lines that have been drawn to incredible thinness.

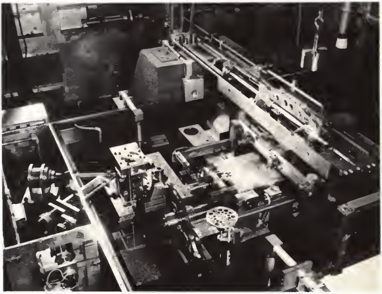
A diffraction grating, then, is a piece of metal-coated glass, brought

to a very high polish. It has thousands of parallel lines — sometimes as many as 200,000 — which have been ruled with the hardest substance known to man — a diamond. On such a mirror there may be anywhere from 30,000 to 40,000 lines to the inch.

This is the perfect instrument for analyzing light waves that are 1/50,000th of an inch long. The diffraction grating will measure their length to an accuracy of one-trillionth of an inch. The wave-length is determined by the number of lines that the rays cover.

Materials that are to be inspected by the spectrograph are reduced to vapor and an electric current is passed through them. Intense heat (7,000 degrees Fahrenheit) from an electric arc breaks down the substance into its atomic constituents. The impact of electrons (negatively charged atomic particles) from the currents produces light which enables the spectrograph to register the desired information. Thus the substance is identified.

The longest and most exact diffraction gratings known are prepared by an engraving machine perfected at the Massachusetts Institute of Technology Spectroscopy Laboratory in 1958 after ten years of research.



This engine for spacing the grooves in diffraction gratings is controlled by light waves. Gratings of unsurpassed quality and up to 10 inches in length have been prepared with this M.I.T. machine.

This machine is the first to employ electronic controls to assure accurate engraving of the gratings. It uses a fine diamond point to make tens of thousands of grooves on aluminum-coated glass. These grooves are about 1/10,000th of an inch deep, and they are parallel with an accuracy that exceeds 1/millionth of an inch.

To control the engraving process, light is obtained from mercury atoms produced in an atomic reactor that transmutes gold into mercury. If the slightest imperfection turns up in the grooves, the resulting wavering of the light rays is picked up by a photoelectric cell which sets in motion an electronic mechanism that corrects the course of the diamond.

The engraving machine is about the size of a grand piano and its parts are immersed in an oil bath as protection against dust. Whereas 8 inches was the greatest length of earlier diffraction gratings, this machine may be able to make gratings twice as long. This would make it possible to get more information about the structure of atoms and the stars. For example, it may be feasible to mount the new improved gratings in satellites to study our solar system without having the observations obscured by the earth's atmosphere.

USES IN ASTRONOMY

Spectrum analysis is invaluable to astronomers because of the wealth of information it provides about the stars. The temperature of a star, for example, can be determined from its color. Changes from dull-red to yellow or white or blue-white indicate increasing temperature.

As the temperature of a surface area rises, the amount of light given off increases. Knowing the distance, temperature, and apparent brightness of a star, an astronomer can calculate the approximate size of some stars. Or, if he knows the size, temperature, and apparent brightness, he can calculate the distance of the star from the earth.

Through a study of what is known as the "Doppler effect," from the name of the man who first formulated the principle, scientists can use spectrum analysis to analyze the motion of the stars.

Stars moving toward the earth move into the light waves they direct toward the earth. Consequently the waves shorten and come closer together. The slight shortening shows up on the spectrum as a shift toward the blue (short wave) band.

If, on the other hand, the star is moving away from the earth, its light waves become longer and the spectrum shift is toward the red band.

Astronomers derive interesting conclusions from this information.

The world's largest telescope at Mount Palomar, California. Its huge reflecting mirror, with a diameter of 200 inches, weighs 19 tons and took 20 years to construct. Through the use of an electronic image converter it will become possible to extend the telescope's range from 2-3 billion light years to 6-9 billion.

By measuring the shifts in a star's spectrum they can tell the speed at which the star is moving. Another bit of fascinating information is that the spectra (spectrums) of the fainter galaxies are shifting consistently toward the red — sometimes at the rate of 37,000 miles an hour.

This would seem to indicate that the universe has been getting larger and larger. Scientists call this the theory of "the expanding universe."

ARTIFICIAL LIGHT

Ever since the days when man lived in caves, he has had to create artificial light for use whenever and wherever natural light was not at his disposal. This is the principle of artificial light: when substances are heated to gradually increasing temperatures, they send out shorter and shorter waves. When the waves reach the lengths characteristic of the visible light band, we get artificial light.

The test of artificial lighting effectiveness is this — the less energy consumed as heat instead of light, the more efficient the light source is. Wood, candles, oil, gas and electric light have all been used in the quest for good artificial light. Each time a new lighting element was introduced, there was clear improvement; but even electric light, which was properly hailed as a great step forward when it was first introduced, makes up no more than 12 per cent of the energy that flows through an electric current.

ELECTRIC LIGHT

In an electric bulb the current is supplied to a filament. As the filament heats up, it glows and becomes incandescent (white-hot). Thus, electrical energy is transformed into light energy — visible light rays. To prevent the filament from burning out quickly, a vacuum is created in the bulb which deprives the filament of contact with oxygen.

Thomas Edison's first practical electric-light bulbs worked with a carbon filament. Such a filament is reasonably long-lasting because carbon has a relatively high melting point. But carbon slowly evaporates under great heat. As the carbon atoms left the filament and moved to the inside of the glass wall of the bulb, the glass slowly turned darker and absorbed some of the light.

In 1906 the General Electric Company assigned a research team under the direction of Dr. William D. Coolidge the task of finding a better kind of filament material. It took the scientists four years to perfect the far superior tungsten filament. Every year a billion dollars is saved on lighting bills through the use of this improved filament.

The diameter of this tungsten filament has to be accurate to a millionth of an inch. In some cases, one pound of tungsten is drawn out into 40 miles of wire.

Another distinguished scientist, Dr. Irving Langmuir, also made important improvements in the electric bulb. He found that by introducing an inert gas into the tube, a brighter light was obtained. He also discovered that if a longer filament was used and coiled into a spiral, the resulting light was more efficient. These improvements resulted in lower rather than higher electrical costs. Today a bulb of a given wattage costs one-third of its 1910 price and gives ten times as much light.

IMPROVED ARTIFICIAL LIGHT

One of the remarkable features of modern research is the ingenuity with which uses have been found for rare elements that were once considered of no value. Neon, for example, is an inert gas, which forms no compounds. It occurs in extremely minute quantities in the earth's atmosphere and is obtained commercially as a by-product in the manufacture of liquid air.

Yet scientists found that neon gives excellent light for certain purposes. First the air is pumped out of a glass tube; then a tiny amount of neon is introduced. When an electric current is passed through the tube, it lights up with a pleasing orange-red glow. Using a tiny amount of mercury vapor gives a blue light; vaporized sodium gives a yellow light; adding a little of both gives green light.

All these forms of vapor lighting are free from glare, and have thus found valuable application in highway and street lighting, in airplane beacons under foggy conditions, in motion-picture sound apparatus, and in some television processes.

Sodium-vapor lighting is much more efficient than "white" electric light and is used to good advantage. Mercury-vapor lamps, which give off a whitish-blue light, are also highly effective. When operated with a sufficiently powerful current, they provide light that is 25 times brighter than that supplied by the conventional incandescent lamp.

Unfortunately these mercury-vapor lamps tend to blacken rather quickly, even when quartz is used instead of glass.

LUMINESCENCE

The greatest modern improvement in lighting, however, was suggested by living creatures which provide light from their own bodies. Such organisms, which liberate light with very little heat as the result of internal chemical changes, are said to be "luminescent."

The one-celled protozoans give off light that can be seen miles away when great myriads of them are grouped together. Some types of sharks have luminescent bellies that help them sight their prey in the blackness of the ocean depths. Other types of deep-water fish have "headlights" in their eyes to enable them to see their way in depths where the sun's rays do not penetrate. Still others are luminescent devices for protection.

Moths, fireflies, and glow-worms are among the land-based creatures that have their own source of light. Some types of beetles, grubs, and even bacteria are also luminescent. Though the amount of light produced is slight by absolute standards, it is large in a relative sense. Some of these tiny creatures waste only about 2 per cent of their energy in giving off light. So they are incomparably more efficient than man's vaunted electric light.

How does science explain this phenomenon? The first isolation of a specific light-producing substance took place in 1886 when a chemical substance was extracted from luminescent clams and named "luciferin." It was found that when luciferin was oxidized ("burned") by an enzyme (a complex chemical substance that initiates a specific chemical reaction), light is given off. The enzyme was named "luciferese."

In the lower forms, such as bacteria, more luciferin is automatically formed as it gets used up. In the higher forms, the nervous system controls the functioning of the luciferin gland. This substance can also be oxidized in the laboratory and made to glow. A complex form of luminescence occurs in certain types of fishes which are not luminescent themselves but have special "pockets" in which they carry luminescent bacteria which live on them. In some cases, the guests repay this hospitality by killing their hosts.

Luciferin works only in the presence of moisture. Scientists have found that after keeping a quantity of luciferin for over a quarter of a century, it began to glow as soon as they applied moisture to it. In World War II, luciferin was prepared in synthetic form and used for sea-rescue work. The light rays given off by luciferin have wave-lengths that fall inside the spectrum band of visible light.

PHOSPHORS

But luminescence is found in inorganic substances as well. When they are subjected to some kind of electromagnetic radiation — say ultraviolet rays, gamma rays, X-rays — they release the received energy in visible light rays.

These are the "phosphors." Some are fluorescent — as soon as

they are subjected to radiation, they emit light; as soon as the radiation is stopped, they stop liberating light. Other phosphors are phosphorescent — on being subjected to radiation, they do not give off light at once. Instead, they store up the radiation and later release it for a comparatively long time.

Artificial phosphors are much more efficient than those found in the natural state. This is due to the fact that the chemical composition of an artificial phosphor can be tailored to have certain desired qualities, such as the color of the light emitted, its duration, etc. Minute amounts of impurities have to be added to get the effects wanted.

The most familiar use of phosphors is in fluorescent lighting, which is an improvement on incandescent electric light in a number of ways. The inside of the glass tubing is coated with a phosphor—usually zinc sulfide or a tungsten compound. A tiny amount of mercury vapor is inserted into the tubing.

When electric current is supplied to the tubing, the vapor gives off bluish visible light as well as violet and ultraviolet rays which are invisible. The phosphor, which may be drab and almost colorless in appearance, in effect converts the ultraviolet rays into visible light rays.

What are the advantages of fluorescent lighting? The visible light rays emitted have wave-lengths that are fairly close to the wave-lengths of the visible light rays in sunlight. This is not so true of the wave-lengths of the rays from incandescent electric light. Consequently there is less glare from fluorescent light; less wattage is needed, and less heat is generated.

From the point of view of converting electrical energy into light, fluorescent lighting is about three times more efficient. The tubes are also more durable than incandescent light bulbs.

Among the other uses of phosphors are: coating X-ray screens and the inside of television tubes; making luminous instrument dials and watches; and preparing dyes that make paint more brilliant.

One of the most interesting uses of phosphors is in the ultraviolet flying-spot microscope described fully on page 69. This instrument uses two picture tubes, one for visual observation and one for photography. The former is coated with an orange phosphor, which gives a long afterglow and thus aids observation. In the photographing process a short afterglow is desirable, and this is produced by a blue phosphor.

ELECTROLUMINESCENCE

This latest use of phosphors employs panels of flat glass that are a foot square and contain phosphor crystals embedded in plastic. On

the outer side is glass which acts as one of the electrodes by having a coating of thin, transparent material that conducts electricity. On the inner side is the other electrode, made of aluminum.

When the current is turned on, the phosphors are stimulated by the electrical field to emit light. Through the use of certain kinds of phosphors, it is possible to change the color of the light by changing the electrical frequency. It is also possible to increase the brightness of the light without creating glare or shadow by stepping up the voltage.

Another advantage of panel lighting is the flexibility in placement of light sources. Electroluminescence lends itself to many novel ideas about comfortable and elegant ways to furnish living space. There is a strong prospect that this lighting method can be combined with television, using large flat screens placed on a wall.

The phosphors used have to be of exceptional purity; a few impure parts in a million will "poison" the phosphor. The most favored materials are zinc sulfide and silicon carbide.

3. The Ways We See

Of all our senses, the ability to see is the most precious. It is an ability that we take for granted; but we would appreciate it more if we realized the miraculous efficiency and delicacy with which the eye operates. Vision as we know it is the product of an evolutionary process that took millions of years, beginning with the development of light-sensitive cells in rudimentary organisms.

One of nature's most remarkable adaptations in the field of vision is the placement of eyes in animals. Hunting animals have frontal eyes, geared for attack; hunted animals have their eyes on the side, as efficient protection. (The cat has frontal eyes; the mouse's eyes look sideways.)

Another remarkable type of vision is found in the compound eyes of insects. The dragonfly, for example, has "bifocal" eyes. Each of its eyes has some 30,000 lenses. This arrangement enables the insect-eating dragonfly to see distant objects in motion as well as nearer objects which are stationary. As an aid to efficient hunting, it can swivel its head almost 360 degrees and can turn it up or down.

Our ability to see is completely dependent on the presence of visible light rays. The fewer rays that are present, the less we can see. Where there are no light rays, as in the case of complete darkness, we are unable to see anything.

When we look at an object, photons from sunlight or artificial light strike the object. Some of these photons bounce off the object — that is, are reflected back into the eyes of the observer. The eye lens has the job of collecting the rays of light and bringing them to a focus on the retina.

The lens, which is in the front of the eye, is made up of elastic tissue and attached to ligaments that keep it in place. When we have to see objects close up, the grip of the ligaments relaxes, so that the lens takes on a more curved shape to converge light rays that are coming from the object and are spreading apart. This adjustment of the lens focusses the rays sharply and enables us to see nearby objects efficiently.

However, when we have to see objects at a distance, the grip of the ligaments tightens, causing the lens to assume a flatter shape and diverge the parallel light rays that are coming from the object. This opposite adjustment of the lens likewise has the effect of focussing the light rays sharply, enabling us to see distant objects efficiently.

In most cases, as people get older, the lens tissue hardens and is not capable of making flexible adjustments. When this happens, it becomes necessary to use artificial lenses in order to make the adjustments which the eye lenses can no longer make.

The eye lens brings the light rays to a focus on the retina. This is a layer of light-sensitive cells where light rays are converted into electrical impulses and sent to the brain. (This miraculous process, then, converts light energy into electrical energy.)

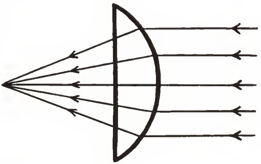
The retina is made up of nine layers containing over 130,000,000 light-sensitive cells. They are all connected with the main optic nerve by means of fibers that convey the impulses to the brain. The brain's reception of the impulses completes the act of "seeing."

The conversion of light rays into electrical impulses in the retina is made possible by a purple pigment which is made up of protein matter and Vitamin A. (This explains why people who have an inadequate amount of Vitamin A see poorly in dim light.)

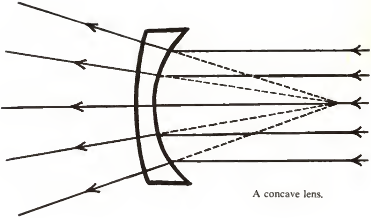
HOW DEFECTIVE VISION IS CORRECTED

A lens, whether natural or artificial, is a device for bending visible light rays, causing "refraction."

A convex lens has its widest outward curve in the center and then tapers inward toward the ends. When parallel light rays (perpendicular to the lens, as in the chart below) strike the lens, they are bent together (converge). The place where they meet is called the "focal point."



A convex lens.



A concave lens.

A concave lens is just the reverse — with a thinner curve in the center than at the ends. When parallel light rays strike it, they diverge — bend outward. The most complex optical instruments, such as the microscope and telescope, operate by elaborations of the principles of convex and concave lenses.

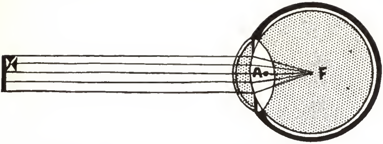
The distance between the lens and the focal point is called the "focal length" or "focal distance." In microscopes, opera glasses, and other optical instruments the focal length can be adjusted to give the sharpest focus for the viewer's eyes. The focal length which gives the sharpest image is said to put the instrument in focus.

What do we mean when we say a person is nearsighted? Diverging rays from a nearby object are efficiently refracted and satisfactorily focussed on the retina. But when it comes to seeing objects at a distance, the parallel rays from the distant object focus before they reach the retina. (The focal length is too short.) The result is that the retina does not produce a clear image.

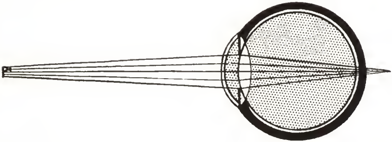
This is corrected by using a concave corrective lens. By causing the light rays to diverge to the necessary degree, it increases the focal length by the amount needed to produce a clear image.

When a person is farsighted, his eyes bend light rays too little. (They have low refractive power.) Rays from distant objects are mostly parallel (see the chart below) and the eye lens has no trouble focussing a satisfactory image on the retina.

But when nearby objects are viewed, the diverging light rays are not bent in time for the eye lens to focus a clear image on the retina.



When a person is nearsighted, parallel rays from distant objects focus before they reach the retina.



When a person is farsighted, diverging light rays from nearby objects come to a focus beyond the retina.

(The focal point in this case is somewhere beyond the retina. The focal length is too long.)

In this case a convex corrective lens is prescribed. This makes the parallel light rays converge soon enough to shorten the focal length just the right amount needed to focus a clear image on the retina.

DEVELOPMENT OF SPECTACLES

As far back as 2300 B.C. the Chinese were familiar with the use of rock crystal, quartz, topaz and the like to aid vision. But they do not seem to have started using glass lenses in the form familiar to us until about 500 B.C.

The reasons for using glasses were not always utilitarian. Some-

times they were worn to bring good luck, or to indicate that the wearer was prosperous or belonged to a prestige profession.

The study of light refraction, which, as we have seen, is the underlying principle of corrective lenses, made very slow progress for centuries. In medieval times the Arabs contributed valuable discoveries about the structure of the eye and the properties of light. When their work came to the attention of European scientists, interest in using lenses was stimulated. Roger Bacon, for example, wrote in the thirteenth century that spectacles are "useful to those who are old and have weak sight." The modern German word for glasses (*Brillen*) is derived from beryl, which was used for some of the earliest spectacles made in the fourteenth century.

By 1500 Nuremberg had a guild of master spectacle makers. England's Worshipful Company of Spectacle Makers — still in existence — was formed in 1629. Spectacles were not individually prepared on the basis of prior examination as they are today. Instead, a buyer tried on a number of pairs until he hit on one that was reasonably satisfactory. Many of these spectacles came with a handle (instead of ear-pieces) and were used only occasionally. By this time it was known that nearsightedness can be corrected by concave lenses, and farsightedness by convex lenses. Pince-nez glasses, worn on a chain, did not come into fashion until the eighteenth century.

In 1784 Benjamin Franklin designed the first pair of bifocal lenses. These have been greatly improved in our own time, and trifocal spectacles are made most ingeniously to serve special uses. Even quadrifocal lenses are also made occasionally.

As the science of optics advanced in the nineteenth century, the fitting of lenses became more and more accurate. The most important new device was Helmholtz's ophthalmoscope, which made it possible to examine the interior of the eye.

SIGHT IN SPACE

Turning toward the future, scientists foresee that venturing into outer space will create novel visual problems for man. Since space is a near-vacuum, it contains no objects that reflect sunlight. In this black region the pupils of unshielded eyes would have to be open to their fullest extent to accommodate themselves to the surrounding darkness.

Only the spaceship itself would reflect visible light rays, and turning the eyes in the direction of the sun, once the traveller is above the earth's atmosphere, would carry a serious risk of blindness. Consequently spaceships will have windows of specially prepared glass to

minimize this danger. In addition, the spaceman's equipment will include some means of protecting his eyes.

Some scientists speculate that as space travel becomes practical, man's eyesight will evolve in ways that we can only guess at now, to become accustomed to the conditions of life in space.

POLARIZED LIGHT

Light waves vibrate in all directions at right angles to the direction in which the light is travelling. (This is called "transverse" motion.)

The result is that when light is reflected from an object, the light rays spread out in all directions. This often causes glare which is troublesome and may be dangerous when clear vision is needed.

When the light waves oscillate in only one direction, this light is said to be "polarized." We can polarize light by using glasses made with special lenses of a plastic whose molecules line up vertically. Light rays that are vibrating vertically are admitted by the lenses; light rays that are moving horizontally are shut out. As this cuts down glare considerably, it is very useful in sun glasses, automobile headlights and cameras.

If it is necessary to cut down glare even more, this can be done by using double polaroid lenses, one of which can be rotated to modify the polarization as desired. (Incidentally, if one lens is set to receive only vertical light, and the other lens is set to receive only horizontal light, then no light at all is received.)

COLOR

Color adds much to the beauty of our surroundings. It also sets science many knotty problems, some of which are far from solved.

When we see several colors at the same time, we are simultaneously receiving two or more types of visible light rays with different wave-lengths and their corresponding frequencies of vibration.

What makes it possible to distinguish the colors in the visible color spectrum is this: the degree to which a light ray will be bent by a prism depends on its wave-length. The longer the wave-length, the less the light ray will be bent. Red light has a longer wave-length than violet light; therefore red light rays are bent less than violet light rays.

The color values we assign to colored objects are ordinarily the colors they will reflect to the observer under sunlight. A red object reflects to our eyes only the rays of sunlight that have red wave-lengths. It absorbs all the other colors. A blue object reflects only the rays of sunlight which have blue wave-lengths; and so on.

What about white, black, and gray? Are they colors? Technically,

Courtesy, Union Carbide Corporation

COBALT-60 TAKES ITS OWN PORTRAIT: Here a cobalt-60 source furnishes the light for its own picture, as it is being moved in an underwater storage area. Cobalt is often used in cancer therapy equipment and in making radiographs to determine flaws in industrial castings.

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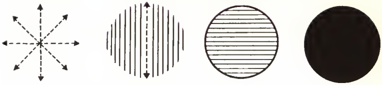

The figure at the extreme left represents the vibration of light waves in all directions, the way that light usually behaves. The next figure shows how vertical polarizing shuts out all but vertical light rays. The third figure shows how horizontal polarizing shuts out all but horizontal light rays. If a vertically polarized lens is superimposed on a horizontally polarized lens, or vice versa, all light will be shut off.

no. White is not really a color; it is the blend of all the visible spectrum colors. It is a color only in the sense that it is the color of daylight. Black is what we see when we view an object that absorbs nearly all light rays, of whatever color. In complete darkness, no light is available to be reflected; so no color is to be seen. Black is the absence of light. As for gray, it preserves a neutral state among all possible colors; none of the colors of the visible light spectrum can be distinguished.

All sorts of complications can arise from varying conditions. The color we distinguish may vary according to the *source* of the light rays reflected from the object. For example, the incandescent electric-light bulb emits very little blue (short-wave) radiation. Consequently it cannot reflect blue light. Hence, an object which looks blue in daylight because daylight reflects blue light, will look black under electric light because the object will absorb all the light that strikes it.

Again, the apparent colors we distinguish are affected by our *means* of receiving light. If an observer looks at a blue object through red lenses, the rays of blue wave-length cannot pass through the red lenses. Consequently, even though the blue object is reflecting blue light rays, these cannot reach the eyes of the observer. Equipped with the red lenses, he sees the object as black.

If the surface of an object is highly polished, it will reflect back all the visible light rays that strike it. As none of the rays have been absorbed by the object, it looks white.

On the other hand, what happens with a piece of coal is just the opposite: it will absorb all the light rays that hit it, and our eyes will register "black" — the absence of light. If an object absorbs some rays and reflects others, we will see only the colors of the rays that are reflected, not the ones that are absorbed.

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Objects differ in their ability to reflect light that falls on them. The lighter the color of the object, the more light it will reflect. Whatever light strikes an object and does not get reflected, is of course absorbed by that object and heats it. This explains why light-colored clothes are more comfortable than dark for summer wear.

The thickness of an object will also affect its apparent color. The thicker an object is, the more light rays it absorbs, and the darker its color seems. In the case of a thin object, more of the light that falls on it will be reflected, conveying more of an impression of a light color.

INSTRUMENTS THAT USE LENSES

The chief conclusion we derive from studying the relation between color, light and vision is that our eyes, miraculous though they are, can often be the victims of appearances. And there are other ways in which our vision is unsatisfactory.

For example, we retain an image of an object only as long as it is before our eyes. We cannot recall the image at will, except in memory and in imagination. The camera gives us a permanent image which can be looked at repeatedly even when the object is not present.

As objects get smaller and smaller, we find it progressively more difficult to see them clearly, until we cannot see them at all. The microscope makes it possible for us to see objects that are invisible to the unaided eye.

As objects get further away from us, we have the same difficulty in seeing them. Beyond a certain distance, we cannot see them at all. The telescope enables us to see distant objects — even those that are separated from us by vast distances.

In the case of all three instruments, we get the desired effect by using some kind of lens with light. Sometimes these lenses are quite different from our conventional notion of a lens. And the light used is not always visible light. But, as we shall see, there is convincing logic in the scientific ingenuity that devises these novel methods.

THE CAMERA

In many respects the camera operates like the human eye. For example:

Like the pupil of the eye, the opening at the front of the camera lets in light.

The camera shutter, which admits light only when a picture is being taken, works like the eyelid.

The camera diaphragm works like the iris of the eye — it regulates the size of the opening.

At the back of the film there is a plate or film which is coated with a light-sensitive chemical. This serves the same purpose as the retina; the image is focussed on it.

The light which enters the camera passes through a glass lens which has the same function as the lens of the eye. When the camera lens is moved backward or forward, the effect is the same as when the eye lens changes its shape to accommodate itself to the distance needed for proper focussing.

When the shutter of a camera is clicked, the film inside is exposed to light. The film is covered with a gelatin emulsion which contains crystals of silver bromide or other silver salts. (Some types of silver-salt crystals are 1/250,000th of an inch in diameter. A square inch of film may contain one trillion crystals. Forty crystals can fit into the thickness of the gelatin layer though it is less than 1/1,000th of an inch thick.)

The light has a chemical effect on the crystals, which react (in some manner not understood) with impurities embedded in the gelatin. When the film is "developed" (subjected to chemical processes in a dark room), the crystals which received light turn into silver; the crystals which did not receive light do not change. A permanent image, with more or less strongly contrasted light and dark areas, is produced. The result is a negative, with the light parts of the photographed object showing up on the negative as dark, and the dark parts of the object showing up as light. A positive print is then made from the negative and on this the original light-and-dark tones are restored so that it looks like the photographed object.

Color film is even more remarkable. It may contain as many as seven layers, each one 15/100,000ths of an inch thick.

Color photography operates with mixtures of the three primary colors. (There are several theories of what the primary colors are. In this case, red, green and blue are used.)

In order to pick up these primary colors, color film has to be coated with a number of layers, and it has to be developed several times with intervening dyeing processes. Finally, white light is directed on the film to bring out the various colors of the photographed object. While all this sounds extremely complex, it is carried out with automatic machinery.

A motion-picture camera is a specialized camera which takes in quick succession a great many pictures. These, after developing, are projected so rapidly on a screen that the viewer is unaware he is seeing a series of individual images. In the course of a single hour a viewer sees 87,500 pictures.

(The same principle is utilized in the stroboscope, a revolving disk with openings through which the passage of light can be viewed. If a series of pictures is placed in the apertures, their rapid appearance and disappearance creates an illusion of motion.)

Special high-speed photography works even more rapidly, roughly forty times faster, with a thousand shots per second.

THE MICROSCOPE

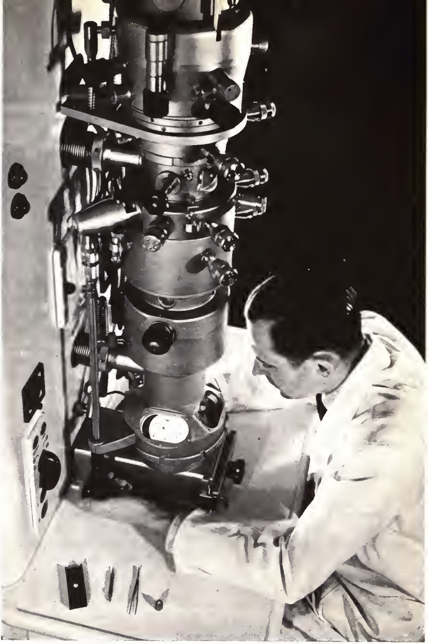
The magnifying power of the microscope results from the apparent enlargement of an image when it is placed inside the focal length of a lens. The earliest microscopes were crude affairs using a single lens. But toward the end of the sixteenth century Zacharias Janssen made the first compound microscope. It was quite simple, with two lenses mounted in a brass tube 18 inches long to collect and focus light rays. In 1610 Galileo made an important improvement by introducing double tubes to provide better focussing. Another Italian scientist, Campini, discovered how to grind lenses to any desired curvature; this added enormously to the efficiency of the microscope — its magnifying power increases as the lenses are curved more sharply.

Yet, despite these and many later improvements, the microscope was not really exploited as a research tool until well into the nineteenth century. It was the microscope that made possible the great advances in preventive medicine in that century. Pasteur's formulation of the germ theory of disease, the most important single step in the history of medicine, arose from his work with the microscope.

The modern compound microscope has two sets of lenses. One set, near the object viewed, is called the "objectives." The other set of lenses, at the top of the microscope, is called the "eyepiece" or "oculars."

Each set of lenses is in a tube, with the eyepiece tube inside the objective tube. There are various ways of sharpening the focus of the instrument, the most common being to turn the eyepiece tube so that the microscope is lengthened or shortened as needed. The purpose of the two sets of lenses is to step up magnification: one stage of magnification is achieved in the objectives, and this magnified image is enlarged still more in the eyepiece.

Such an instrument proved highly satisfactory for a long time, making it possible, for example, to observe bacteria which have a diameter of 1/250,000th of an inch. Yet the highest magnifying power of the optical microscope is about 2,500 times, and many scientists began to regret that they were unable to view small objects (viruses, for example) which were beyond the reach of the microscope.



The electron microscope replaces the glass lenses of the optical microscope with an electron beam controlled by powerful electromagnets. This sensitive instrument has extended the range of minute objects observable in scientific research.

The object becomes too blurred to be distinguishable when the distance between any two points on the "target" is less than half the wave-length of the light used in the microscope. Consequently, in order to see smaller objects than can be seen by visible light, we need to operate with some form of radiation *which has a shorter wave-length.*

Ultraviolet light answers the purpose up to a point. Having a shorter wave-length than visible light, it provides a magnification of 5,000 times. It is true that ultraviolet rays are invisible, but if they are used with special camera equipment, we can photograph the object and obtain valuable information from the resulting photographs. It is also possible to convert ultraviolet light into visible light by electronic methods.

X-ray microscopes answer still another need, as they give us an image of the inside of an object, thanks to the high penetrating power of X-rays. The wave-lengths on which they operate are 10,000 times shorter than the wave-lengths of visible light rays. This makes it possible to use the X-ray microscope on an object with a diameter of 3/10,000,000ths of an inch. (For more about X-rays, see pages 133–143.)

THE ELECTRON MICROSCOPE

This remarkable instrument, one of the wonders of twentieth-century science, dispenses altogether with conventional lenses. Operating on anywhere from 40,000 to 100,000 volts, it magnifies over 100,000 times. In fact, magnifications of 300,000 times have been claimed for some German electron microscopes. And scientists are confident that the efficiency of this instrument offers room for further improvement.

Electrons are negatively charged atomic particles. The wave-lengths of electron streams are much shorter than the wave-lengths of visible light rays, as much as 100,000 times shorter. Consequently, scientists reasoned, it should be possible to use an electron beam to magnify objects that cannot be seen with the optical microscope. The earliest electron microscopes were crude and disappointing. But a series of improvements brought them to their present stage of high efficiency.

A powerful electric current in conjunction with electronic equipment produces an electron beam which is trained on the object and then forced through the magnetic fields of powerful electromagnets. These magnets force the beam to widen as it shoots through a vacuum.

The continual widening of the beam produces a virtual enlargement of the image, which, however, is still invisible. But it can be made visible by being projected on a fluorescent screen. It can also be made

The "Cascaded Photosensitive Image Intensifier," which was developed by U.S. Army scientists to gather reflected starlight or diffused light from skyglow falling upon the objective. The device will enormously increase the range of visibility at night.

visible by being focussed on a camera lens, which has the further advantage of contributing additional magnification of the already enlarged image. In order to allow the electrons to pass through the slide on which the object is placed, the slide is made with a thickness of no more than 2/1,000,000ths of an inch.

In the comparatively few years of its existence, the electron microscope has rendered invaluable service. It has enabled scientists to observe more than a third of the 300 or so known viruses. Observation of these organisms is the first step toward isolating them and discovering ways of fighting the diseases they cause. It is an important weapon in the struggle to discover the cause of cancer.

Many important details about the smaller bacteria have been learned for the first time by the use of the electron microscope. It has also enabled scientists to view for the first time the way in which the tiny organisms known as "bacteriophages" attack and destroy bacteria. Because the electron microscope makes it possible to examine molecular

structure, it has played an important role in many industrial processes, such as the manufacture of synthetic rubber, the improvement of textile fibers, and the study of how metals react to high-stress conditions.

THE TELESCOPE

Although our planet is a mere speck in the universe, man has been able to acquire a surprisingly large body of knowledge about other parts of the universe. Much of that knowledge we owe to the telescope, which was invented in 1608 by Hans Lippershey and has undergone countless improvements by Galileo, Newton and other great scientists. It was Galileo who first observed the "spots" on the sun and the "mountain ranges" on the moon and discovered the satellites of Saturn. That he was able to reach millions of miles into space with the crude instruments of his day gives us some idea of the power of the telescope.

In principle, the telescope is a long tube with an objective lens and an eyepiece. Magnification depends a good deal on the state of the weather. When the layers of the atmosphere are unequally heated, the light from the stars and other bodies in the heavens takes on a shimmering quality which is very unfavorable for clear viewing; magnification makes matters worse.

The great telescopes depend much more on their reflecting mirrors than on magnifying as such. These enormously enlarged mirrors gather and intensify the faint light from distant objects and thus bring into clear focus images that would be hopelessly blurred or invisible on smaller telescopes.

Observatory telescopes replace the eyepiece with camera equipment. This has many advantages. The human eye is tired by long vigils, whereas the observatory camera produces a better image from long exposure. Besides, the picture is permanently available for repeated study and comparison. Such a telescope has to be guided by clocks that keep the instrument shifting in phase with the rotation of the earth and the apparent westward motion of the stars. The telescope is used in combination with other instruments as well, the most important of these being the spectroscope and the spectrograph.

THE MOUNT PALOMAR TELESCOPE

The largest and most powerful telescope in the world is located at Mount Palomar in California. Using a huge reflecting mirror that has a 200-inch diameter and weighs 19 tons, this amazing instrument was twenty years in the planning and building, at a cost of $6,500,000. The grinding of the lens alone required eleven years.

The Palomar telescope, with its magnification of 600,000 times,

gives us information about the size, mass, density, velocity and composition of stars some of which give us a light as feeble as that of a candle at a distance of 40,000 miles. In some cases the telescope picks up light rays that started travelling a billion years ago. It also records the movements of nebulae (clusters of stars and gases) that are moving away from the earth at the rate of 60,000 miles a second. This remarkable instrument has increased eightfold the portion of the universe which is accessible to study by the telescope.

Although the Palomar telescope has subjected billions of stars to scrutiny, this still represents only about one millionth of all the stars in the universe. The so-called "fixed stars" are so far away from us that even the most powerful instruments do not make them look any larger or clearer.

The universe, the astronomers tell us, has room for two billion "Milky Ways," including some much bigger and with far more powerful suns than our own.

So, like all other scientists, the astronomers are always looking for better research tools. The electronic image converter, which has been used to step up the powers of other optical instruments, is expected to increase the brightness of the Palomar telescope by 10,000 to 20,000 times.

The effect would be to give the 200-inch mirror the range of a 2,000-inch mirror. It may well be possible to extend the range of the Palomar telescope from 2–3 billion light years to 6–9 billion light years. Such an increase would be due to the fact that the image converter is far more efficient than photographic plates at picking up light photons. Attached to a telescope, the image converter intensifies the faint light of a distant object before it strikes the photographic emulsion.

4. The Mysterious World of Invisible Radiation

When the layman is told that infrared radiation was one of the great secret weapons of World War II, he is baffled. How can invisible rays be detected, measured, put to use — let alone help to decide the fate of great nations? We'll soon see.

The earth is continually bathed in rays that come in from all directions. The only ones we see are those of visible light. On the whole this is fortunate, for it would be maddeningly distracting to see all the other kinds of rays.

When scientific knowledge is not available, man has to do the best he can with common sense, observation, trial-and-error. Long before it was known that heat is infrared radiation, man used heat in rather sophisticated ways. For example:

Greenhouses were used to stimulate rapid growth of plants centuries before scientists understood how the sun's energy affects plant growth. Only 10 per cent of the light rays and the shorter infrared rays are blocked by glass. All the rest of this energy passes through the glass.

When the rays penetrate the glass of a greenhouse, they strike the soil and floors and objects inside. In the process, some of this trapped radiation is converted into long infrared waves. These are heat waves. (The impact changes light energy into heat energy.)

These new, longer radiations cannot escape from the greenhouse, as they lack the energy to penetrate the glass. Consequently, whenever they strike the glass from the inside, they are reflected back to the interior of the greenhouse. Thus the heat from these rays remains in the greenhouse and fosters the growth of the plants.

INFRARED RAYS

The Latin word *infra* means "below." Infrared rays, which are invisible, are that part of the electromagnetic spectrum (page 29) which

is next to the red end of the visible-light band. They move with the speed of light and vibrate with long wave-lengths and low frequency as they travel. A vibration, measured from wave-crest to the trough of the wave and up to the next crest, is called a "cycle." A thousand cycles is a "kilocycle"; a million cycles is a "megacycle."

Scientists have devised various instruments to measure infrared radiation. The bolometer is still considered the best of these. In principle, it measures heat radiation by the effect it has on an electric current. It is so sensitive that it can reveal differences of less than 1/100,000th of a degree Fahrenheit.

Infrared radiation frequencies range from 1 million megacycles to 500 million megacycles per second. On the electromagnetic spectrum this lies between the visible light band, and the microwave band used for radar (see page 29). A good many of the uses to which infrared radiation has been put are dependent on detecting frequencies or differences in frequencies.

Sir William Henschel discovered infrared radiation in 1800 when he saw the temperature rise on his laboratory thermometer placed beyond the red part of the spectrum. He correctly concluded that the heat was produced by invisible radiation.

But further progress in this field was slow, and it took more than a century to put these rays to use. Eventually scientists discovered that a specific infrared wave-length is absorbed by an object according to its chemical composition. This meant that infrared rays could be used to identify chemical substances, and it began the golden age of infrared research. New discoveries and practical applications have followed each other with breathtaking speed.

INFRARED PHOTOGRAPHY

When infrared photography was first attempted about 1925, it proved possible to photograph objects about 60 miles away, even on overcast days when visibility extended only half that distance. The sharpness of the image, under these conditions of the atmosphere, was even more surprising. (When we deal with infrared photography, it requires an effort to dissociate our thinking from the conditions which determine success or failure in using conventional cameras. These of course are related to visible light.)

The light-and-dark values in infrared photographs were equally surprising. For example, meadows and forests came out light, almost white. Rusty iron and dark complexions likewise appeared very light. On the other hand, blue sky and water surfaces were quite dark.

Why these contrasts? The air taken in by the leaves causes the

A landscape photographed with conventional camera equipment.

infrared rays to be reflected, accounting for the pale appearance of the foliage on film. Water, on the other hand, absorbs infrared rays. This gives the water a dark appearance on infrared pictures.

Research revealed that moisture has an affinity for absorbing heat, and that there is a definite relationship between the amount of moisture in the air and the wave-length of the infrared rays that will be absorbed. It therefore became advantageous to design infrared photographic equipment that would operate on this principle.

Since infrared photography differs from conventional photography, it is necessary to use specially prepared infrared film and a special lens. In fact, there are times when it is actually desirable to shut off visible light in order to get a sharper infrared image. Actually, the presence of heat is the most desirable factor: a heated room will provide a better image than an unheated room.

An interesting aspect of night photography is that 75 per cent of the moon's radiation is made up of infrared rays. So moonlight is very helpful, even where the moon is hidden by clouds. (This invisibility has

The same landscape photographed with infrared camera equipment. Note the vastly increased amount and sharpness of detail.

no effect on the infrared rays, of course.) The moon thus acts as a gigantic infrared "searchlight." This was disclosed by research as long ago as World War I.

WARTIME INFRARED USES

In World War II infrared photography was the chief method of getting information about enemy installations. While camouflage can readily deceive the conventional camera, such attempts have little chance of fooling the infrared camera, which gets its image from the heat radiations of an object.

This is the point: every object releases more or less heat radiation because the movement of its molecules emits energy. The amount of radiation depends on certain internal conditions—its color, for instance, or its density (whether it is a solid, a liquid, or a gas), etc.; also on external conditions, as for example, when it is subjected to freezing temperatures or when an electrical current is passed through it.

In any event, molecular action makes it impossible for the tempera-

The soldier simulates study of a map in the dark with the use of a metascope, an improved version of the snooperscope. The metascope is a small viewer equipped with an infrared light source and battery.

ture of an object to be reduced to absolute zero, so that it necessarily follows that there will be a certain amount of infrared (heat) radiation. This radiation can be picked up by an infrared camera.

Camouflage, no matter how skillful, offers no concealment, because there will be some heat emanations, although different perhaps from what they would be if the object were not disguised. The infrared camera, instead of absorbing visible light rays, absorbs infrared (heat) rays. The equipment is so sensitive that it can distinguish by thousandths of a degree contrasts of light and dark.

Thus, when an infrared picture is taken of a parking lot, the cars will reflect heat rays of a different wave-length from those reflected by the concrete. The greater the contrast, the clearer the resulting image. During World War II the infrared camera penetrated the most masterly cover-up of bivouac areas, weapons, forests, tanks, airports, etc. The visual appearance could be disguised, the heat emanations could not.

Infrared equipment has another advantage: being independent of visible light requirements, it operates just as well, if not better, at night. During World War II German tanks were equipped with infrared "searchlights" that picked up objects at a distance of several thou-

sand yards even during cloudy weather or at night. The use of fluorescent equipment made the objects detected by the infrared devices visible.

Since the war's end this technique has been greatly improved and it now functions over a distance of 15 miles. Lead sulfide has been found to be the most important component of such equipment.

Because infrared techniques yield very sharp images, they are ideal for mapping hostile areas and for picking out detail in briefing bombing missions. During the war, reconnaissance planes taking aerial photographs used infrared equipment because they often flew five miles above ground and had to penetrate haze in the atmosphere. Conventional photography could never pierce the haze, but infrared did. Such cameras, costing $5,000 or more, used a lens made of specially treated glass, each piece about the size of a large plate. Infrared equipment was also found helpful in supplementing radar and conventional photography.

SNOOPERSCOPE AND SNIPERSCOPE

Toward the end of the war, some American soldiers had helmets equipped with an infrared device for nighttime fighting. This was the snooperscope, which operated with infrared rays that were converted to visible light rays and enabled the soldiers to see almost as well at night as in broad daylight.

The Germans had similar equipment. The design was so precise that it even took account of the earth's magnetic field. The device consisted of a pocket-sized battery, a tiny transformer, and a walnut-sized motor capable of 10,000 revolutions per minute and good for 300 hours of use.

To test the accuracy of this infrared device, German scientists used it to detect a star in the constellation of Ursa Major that sends out only infrared rays. In the course of these observations they discovered that the rim of Mars looks bigger when scrutinized with infrared equipment than it does under conventional photography. Thus they discovered that Mars has an atmosphere that reflects infrared rays.

The sniperscope was a similar infrared device used with deadly effect by American troops in the Pacific theater of war. In combat the sniperscope made it possible for American troops to see enemy soldiers at night without being seen themselves. The enemy troops, trapped by the infrared rays, were reflected back to the sniperscope, which converted the infrared rays to visible light.

Thus, American soldiers were able to sight a target without being seen in return. The sniperscope has been credited with the American

victory at Okinawa, and it has been estimated that one-third of the Japanese casualties resulted from the use of this device.

From time to time there are meager reports of current military research in the infrared field. In 1958 the United States Army announced that it had perfected an infrared "eye" which gives warning of a gas attack. The device is named "Lopair" — a contraction of "long-path infrared." When contaminating gases cross an infrared beam, Lopair flashes a warning signal and honks a horn. Gases which are colorless and invisible to the naked eye can be detected by Lopair.

The infrared Sidewinder guided missile is named for the Sidewinder snake, which detects its prey by means of infrared-sensitive organs located at the sides of its head. The infrared missile is a powerful weapon against jet fighting planes, as it heads unerringly for their tailpipes and then explodes inside.

INFRARED IN SCIENCE

Astronomers employing infrared techniques have made many valuable discoveries about the chemical composition, heat radiations, and temperatures of the planets and stars. Infrared methods have also been used to advantage in the study of molecular structure, as there is a definite relationship between the arrangement of atoms in a molecule and the wave-length of the infrared rays it absorbs.

Infrared cameras can also be used to scan images. As they do this much more rapidly than the conventional television cameras, they may some day replace them.

The infrared camera can tell us a great deal about the past as well. Geologists and archeologists are among the scientists who use infrared for obtaining information from the terrain they are studying. The age and condition of rocks are the key to much of our knowledge of past eras. But it often happens that layers and fossils are not as clearly outlined as is desirable for dependable information. Infrared photography clears away much of the irrelevant detail, so that the important evidence is no longer obscured. This has made possible some of the most valuable discoveries in the history of archeology.

The fact that infrared analysis can show how much carbon dioxide is being released from a given source has ingenious applications. It is possible, for example, to determine how rapidly a plant is growing by the amount of carbon dioxide it is giving off.

Some years ago this was turned to practical account when a beetle plague struck trees in northern Maine. The infrared analyzer showed which trees were still alive and which were dead. The dead trees were immediately cut down, while the live ones were treated and preserved.

The sniperscope of World War II has undergone considerable improvement. The newer models are lighter, more durable and more versatile, and have a greater range.

INFRARED IN MEDICINE

The most familiar use of infrared rays in medicine is radiation therapy. Infrared rays penetrate the skin readily and have a healthful effect on muscles and nerves. They can be used to stimulate blood circulation, and they sometimes relieve the pain of arthritis and neuralgia.

The ability of infrared rays to pierce the skin makes it possible to use the infrared camera to study the condition of veins and blood vessels. The resulting information can be important in certain types of diagnosis.

The use of the infrared analyzer to check carbon dioxide output has some versatile applications in the field of medicine. During the course of an operation, for example, it may literally be a matter of life and death to detect changes in a patient's breathing. The infrared analyzer is one of the devices used for this purpose.

The breathing of a polio victim in an iron lung is checked in the same way; and in the atomic submarine, the *Nautilus,* the purity of the air supply is checked by use of the infrared analyzer which shows how much carbon dioxide is being given off.

The United Nations unit which is charged with fighting the international traffic in illicit drugs has a valuable weapon in infrared spectrum analysis, which enables skilled researchers to determine the country of origin of any quantity of opium.

INFRARED IN INDUSTRY

In World War II infrared instruments proved to be of great value in the processing of synthetic rubber. Since then they have found more and more applications in industrial work.

Newly painted automobiles, as they are finished, pass through tunnels containing infrared lamps. The warmth of the rays greatly speeds up the drying process.

Ceramics and wood products can also be dried rapidly by the use of infrared lamps. Quick-drying infrared processes are employed in the manufacture of shoes, textiles and paper.

As infrared cameras can convert infrared rays into visible light rays, it has become easy to detect spots that differ in temperature from surrounding areas. Such information is of great value in checking the condition of furnace walls in a steel mill or power plant. If infrared examination shows that some spots in a wall are hotter than others, the presumption is that such sections are in danger of crumbling. Timely repairs will avert the danger.

Infrared detectors are also used in steel mills to hold 100-inch strips of hot steel to minute accuracy.

One of the ways in which railroads prevent accidents is to place infrared detectors on tracks to reveal excessively hot bearing boxes at the bottom of railroad cars. This excessive heat is recorded automatically on a switchman's chart, and when a train passes with this condition, he can pick out the defective part on his recorder chart and arrange for a replacement.

In Los Angeles, infrared analyzers have been used to identify the substances that pass out of an automobile's exhaust pipe. This inspection is part of the struggle against "smog," the idea being to detect hydrocarbons that do not burn completely and therefore create obnoxious fumes.

INFRARED IN CRIMINOLOGY

Infrared photography has provided criminology with techniques that Sherlock Holmes never dreamed of. The infrared camera, for example, can often make the writing on a charred piece of paper perfectly readable.

In a famous case, some writing on an important official document


Infrared radiation is adaptable to a wide variety of uses. Here it is used to warm an incubator to just the right temperature.

was completely obscured by a government stamp which had been obtained illegally. Could the original text be distinguished with infrared methods? It all depended on whether the ink used for the rubber stamp had had an oil base. Such inks reflect infrared rays and will therefore prevent the writing underneath from registering on infrared film.

In this case, the rubber stamp ink absorbed the infrared rays (indicating that the ink did not have an oil base), and the concealed text became readily distinguishable.

Letters, checks, wills and other documents that have been illegally altered can be photographed similarly with an infrared camera in order to detect the concealed or obscured original text. (Unfortunately, infrared rays cannot penetrate inks made with aniline dyes.)

There have been rare cases where infrared techniques were used criminally. During World War II, the Nazis issued £200,000,000 of counterfeit English currency. The job was so well done, thanks to preliminary infrared study of genuine notes, that even the most painstaking analysis could not establish any distinction between genuine notes and counterfeit ones.

At war's end the Bank of England called in the old issues and replaced them with new currency carrying a different identifying characteristic.

A famous stamp forger named Sperati likewise used infrared techniques to make counterfeits of famous philatelic rarities. Again the most refined scientific analyses failed to detect the forgeries. Sperati tenaciously defended himself against legal action by blandly maintaining that his "imitations" were works of art, and that he had made them in order to help collectors of moderate means acquire facsimiles of famous rarities. The courts backed him up!

The story had a curious sequel. A storm went up in the philatelic world as wealthy collectors realized that the value of their costly collections was menaced by Sperati's skillful methods. A group of English collectors therefore purchased Sperati's whole stock of "works of art" for several hundred thousand pounds, in return for his promise to retire from his artistic activities. Sperati kept his promise and retired to live comfortably on the proceeds. Other English collectors, however, were outraged by this evidence that crime occasionally pays handsomely. This started a controversy which is still smoldering.

ULTRAVIOLET RAYS

If ultraviolet rays were to reach the earth with the energy they carry on being emitted from the sun, all life on this planet would be destroyed in a few seconds. Luckily there is a layer of ozone in the stratosphere, between 12 and 30 miles above the earth. Here most of the ultraviolet radiation is absorbed; the remaining part, which reaches us, is mostly highly beneficial.

A trace of the original deadly quality of ultraviolet rays still remains in the case of sunburn, which is caused, not by visible light rays, but by ultraviolet rays. Over-exposure to sunburn can lead to serious illness, and in extreme cases, to death.

Ultraviolet rays have higher energy and shorter wave-lengths than those of visible light (see page 29). The ultraviolet part of the electromagnetic spectrum is next to the violet end of the visible-light band. The discovery of ultraviolet radiation did not occur until 1801.

MEDICAL USES OF ULTRAVIOLET RAYS

It is well known that children who do not get enough sunshine may develop rickets, a disease characterized by bone softening and bone deformity. Essentially rickets is due to a calcium deficiency in the body. Actually it is the ultraviolet content of the sun's radiation which stimulates calcium metabolism and thus make it possible for the bones to develop properly.

What happens is this: the action of ultraviolet rays on the skin causes a substance called "ergosterol" to produce Vitamin D, which is needed by children if they are to have sturdy bones. After scientists discovered the importance of Vitamin D, cod-liver oil was administered as a source of the vitamin. Today Vitamin D is obtained from milk, bread and other common foods which have been subjected to ultraviolet radiation.

Ultraviolet rays are both deadly and beneficial: they are powerful bacteria killers. Artificial ultraviolet radiation is used extensively by

the pharmaceutical industry in sterilizing antibiotics and other products, and is equally valuable in food-processing plants.

Some hospitals use ultraviolet radiation to sterilize the air in their operating rooms. It is likely that eventually all hospitals will be sterilized throughout in this way.

Ultraviolet rays can be supplied very conveniently from mercury arc lamps (see page 39). Small quantities of mercury and an inert gas are put into a vacuum tube. When the current is turned on, it causes a flow of electrons from the mercury atoms. The wave-lengths of this radiation are in the ultraviolet range of the electromagnetic spectrum, and thus we obtain ultraviolet radiation without sunshine. By using the right filters, we can absorb rays of any wave-length that are considered undesirable.

Ultraviolet equipment is also used in diagnosing some diseases where it is necessary to detect infected areas that cannot be seen under visible light. Though the ultraviolet rays are invisible, a revealing image can be projected on a fluorescent screen.

ULTRAVIOLET MICROSCOPES

As we have seen (page 54), the wave-lengths of visible-light rays are too long to provide the enormous degree of magnification required in many kinds of scientific research. Ultraviolet rays, being shorter than visible-light rays, give a greater degree of magnification. The image cannot be seen unless special photographic equipment is used.

The finest instrument of this kind is the superb "ultraviolet flying-spot television microscope," which was inspired by the long-cherished desire of scientists to observe the life-processes going on in the living cell. Deprived of this opportunity, they have had to make deductions from indirect evidence. Much of this work has been brilliant and fruitful, but it has been frustrating too.

A visible-light microscope does not provide enough magnification for this purpose. Ultraviolet rays can give enough magnification, but they introduce two new problems: they would kill the living tissue, and in any event the specimens could not be viewed on slides, as ultraviolet rays are invisible. The images obtained would be available only on photographic film.

However, the ultraviolet flying-spot television microscope removes these defects. It uses a television tube that is coated on the inside with a phosphor that emits ultraviolet rays. The light thus obtained is reflected into the microscope.

The object on the slide is scanned rapidly and continuously by a "flying spot" of ultraviolet radiation. In this way, each point of the

cell is affected by the ultraviolet scanner for such a brief time that there is no harmful effect. Just to be on the safe side, the ultaviolet beam is so weak that any possibility of damage is greatly minimized.

Once the image has been obtained by the scanning process, the rays are intensified enormously by electronic means and then converted into visible light by a picture tube. A second picture tube is used with photographic equipment to provide a permanent record in the form of a motion picture.

Some of these films are more than eight hours long, and show how the cell grows and reproduces; how cell organs move and change; how the cell takes nourishment; how chemical changes take place. One of the most important uses of this machine is the study of human cancer cells.

Prior to the introduction of this remarkable instrument, ultraviolet microscopy had to its credit the 1936 discovery of DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). This discovery has been the source of striking advances in the field of genetics (page 141).

ULTRAVIOLET ANALYSIS

Adulteration of foods can be detected quickly by applying ultraviolet radiation in combination with projection on a fluorescent screen. The adulterated portion will show up in a different color from that of the natural substance. If marmalade, jelly, or fruit juice (and many other kinds of foods) have had artificial coloring matter added without labeling to that effect, ultraviolet analysis will reveal the change.

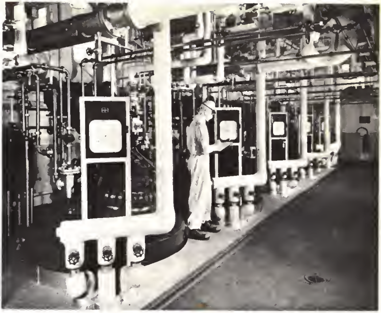
The same technique is used to check the freshness of meat and the fat content of milk and cheese. When drinking water is subjected to ultraviolet tests, pure water does not fluoresce on the screen. On the other hand, any organic matter that may be present will show up as a bluish tint on the screen.

Ultraviolet analysis will also bring out the differences in wines and vintages. If wine has been diluted or tampered with in some way, it is impossible to hide the change from ultraviolet rays.

ULTRAVIOLET CRIMINOLOGY

The use of ultraviolet techniques makes the forger's life a hard one, as each element of a forgery can be examined with the greatest thoroughness.

Each type of paper, for example, fluoresces differently on the screen. Thus the substitution of a document can at once be recognized. If the same type of paper has been used, the expert can check the ink; again differences in ink content are revealed by ultraviolet rays.



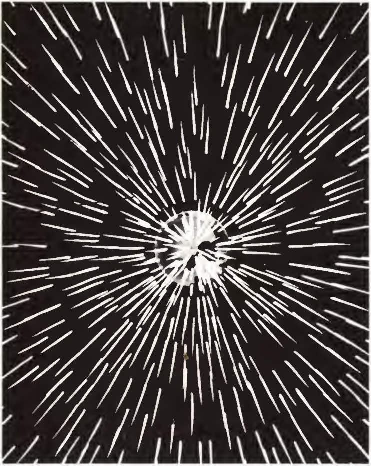
In the last stages of processing antibiotics such as Terramycin and Tetracyn, they are subjected to ultraviolet radiation to ensure a sterilized product.

But suppose the same kind of ink was used for text and signature. Then, in the event that the signature was executed later than the text, this will be demonstrated by the ultraviolet analysis.

Such study will also unearth anything that has been erased or eradicated. In this latter type of examination it is important to use a series of filters, each one of which shuts out waves of some undesired length. Narrowing the wave-length range in this way often reveals valuable details that would elude mixed radiation. The flaws in counterfeit money are shown by the same methods.

The study of forged documents is of great importance in historical research. Ultraviolet examination of historical records and documents has often revealed serious tampering with the original version. In some cases the original text has been altered to the extent of stating the opposite of what was originally written.

Ultraviolet analysis plays a great role in examining the paintings of old masters, or alleged old masters. Study of the underlayers and



Cosmic rays shower down upon the earth in all directions from outer space. Scientists still have a great deal to discover about this form of radiation.

the canvas will often reveal a forgery. Or, if the forger has used pigments made from aniline dyes on a picture which purports to date from a time when these dyes were not available, his fraud will be detected immediately.

Clever forgers will sometimes take an old canvas and scratch off

a worthless old painting, replacing it with a forgery of a masterpiece. However, the vestiges of the original work will show up when ultraviolet analysis is used.

Ultraviolet techniques can also be helpful in the legitimate restoration of old masterpieces that have darkened with age and lost much of their clarity of outline. Ultraviolet examination will reveal the original contours and show the expert how to go about making a faithful restoration of the faded painting.

COSMIC RAYS

Although it is common knowledge today that we are bathed unceasingly in invisible radiation, this information is of comparatively recent origin, dating back no further than 1800. Cosmic rays were the last to be discovered, and they are still the ones about which we have the least knowledge.

We do know that they have the shortest wave-lengths (about 5 trillionths of a centimeter) and highest frequencies, and that they are the most powerful of all forms of radiation. They are able to penetrate through hundreds of feet of solid rock.

Cosmic rays were first discovered in 1903. Scientists soon observed that cosmic radiation increased with altitude. This was confirmed repeatedly — for the first time conclusively by an Austrian team of scientists who ascended 16,000 feet in a balloon in 1912.

Subsequently, Robert Millikan studied this radiation at Pike's Peak, Colorado, and in the Bolivian Andes. Auguste Piccard traced the rays in the stratosphere. Admiral Byrd contributed research on cosmic rays at the North Pole. All came to the same conclusion — cosmic radiation increases with altitude. It was found, in fact, that cosmic rays are a hundred times more plentiful in the stratosphere than they are at sea level. Below the surface of the earth — in mines, for example — the number of cosmic rays decreases still more.

Arthur Holly Compton tried a broader attack on the problem by organizing a group of scientists to study cosmic radiation in eight different regions. They concluded that the rays must come from outer space — hence the term "cosmic rays."

ORIGIN OF COSMIC RAYS

Just where do the rays originate? How do they acquire such high energies? What can we learn from them about the nature of the universe? So far the evidence is meager, baffling, and tantalizing.

There is disagreement among scientists as to whether cosmic radia-

tion reaches us from the sun or from outside the solar system. Among those who hold the latter view, some believe that cosmic radiation may reach the earth from gigantic explosions that occur in our galaxy once in several centuries. The resulting particles would float in the Milky Way for millions of years and some would eventually reach the earth.

Another theory holds that the interaction of the magnetic fields of stars has an accelerating effect on particles of cosmic dust, and that this steps up their energy content.

Still another scientific speculation suggests that particles accelerated by such a process get more and more diffused through interstellar space as they collide with other particles and continue to gain additional energy.

And there are other ingenious guesses, for example, that the sun and the other stars are decaying, and that cosmic rays are liberated as energy is emitted. Another theory holds just the opposite, that cosmic rays are given off when atoms in outer space combine to form compounds.

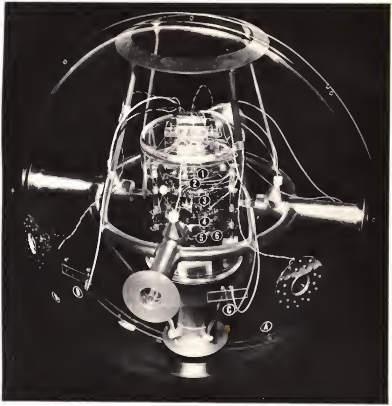
WHAT HAPPENS TO COSMIC RAYS

Scientists distinguish between two kind of cosmic rays. One is the kind called "primary rays." Starting from an unknown source, they travel toward the earth. Their electric charge may range anywhere from one billion electron volts (see page 146) to one billion billion electron volts. These highly charged particles release energy in the form of secondary rays, which in turn decay radioactively and give off gamma and other kinds of rays. So the process continues, with some energy lost at each stage.

It is believed that something like 85 per cent of the primary radiation is made up of protons — positively charged atomic particles. When these collide with the nuclei of oxygen and nitrogen atoms, the result is the formation of mesons, which are unstable and short-lived. As the mesons give off their energy, different kinds of electrically charged particles are formed.

The earth acts as a magnet, with lines of force running across its magnetic field from the North Magnetic Pole to the South Magnetic Pole. The attraction for cosmic rays and other charged particles is strongest near the poles, weakest near the Equator.

But much of this radiation is cut off from the earth by a barrier — the earth's atmosphere. Rays that may have travelled billions of light-years are cut off at this final stage. Here and there some rays from outer space manage to get through occasional gaps in the atmosphere.



A scale model of the "Project Vanguard" artificial satellite. Keyed letters and numbers refer to the following instruments: (A) solar cell for storing data; (B) ultraviolet detector; (C) instrument for measuring temperature; (D) erosion gauge to measure pitting by meteorites; (1) Minitrack transmitter; (2) and (4) instruments for storing data; (3) telemetry coding system; (5) and (6) amplifiers.

WHAT ARE THE EFFECTS OF COSMIC RAYS?

Scientists still do not know enough about cosmic rays to form any conclusions about the effect of this radiation on living creatures. Much of their thinking about the rays is necessarily speculative: for example, is it possible that these rays affect the genes and chromosomes and thus influence heredity factors? (See pages 141 and 197.)

Now and then we get tantalizing hints of the effects of cosmic

radiation. This happened, for example, when French scientists engaged in cancer research tried to magnify small parts of living cells by injecting radioactive tracer elements and then placing them on an extremely sensitive photographic plate to be photographed under the electron microscope. At this point the researchers found that the sensitive plates also picked up the tracks of cosmic rays, ruling out the possibility of achieving worthwhile results.

How do cosmic rays affect the chemical composition of the atmosphere? One such effect is that after primary cosmic rays collide with other particles, the collision sometimes results in the formation of neutrons (atomic particles which are electrically neutral).

Some of these neutrons are captured by nitrogen atoms which are in turn transmuted into carbon 14. This radioisotope (page 169) of carbon is essential to photosynthesis, the process by which plants make their own food.

Cosmic rays also influence the ionization of the atmosphere, and this may affect our health in ways that still require a great deal of exploring. This is why:

An ion is a particle that has an electrical charge — positive or negative. Air ions are molecules of air that have received an electrical charge that originated with cosmic rays or some other radiation.

Some scientists believe that an excess of positive ions in the atmosphere aggravates the symptoms of sufferers from such ailments as gout, rheumatism, sinus infections, asthma and neuritis. An excess of negative air ions, on the other hand, seems to relieve the symptoms. It has long been known that the increase of positive ions noted before thunderstorms has an aggravating effect on these ailments. Experiments performed thus far seem to bear out these views.

Cosmic radiation has added to the problems of astronomers who had calculated that the Milky Way has a diameter of 100,000 light-years and a thickness of 1,000 light-years. It is believed that cosmic rays pick up energy as they pass through the magnetic field of the Milky Way. If this is so, then the Milky Way — according to our present notion of its size — is not large enough to bring about the terrific acceleration of the cosmic rays.

COSMIC RAYS AND SATELLITES

In the lower zones of the atmosphere, as we have seen, much of the energy of cosmic rays is dissipated. But at altitudes of over 120,000 feet this protection is not available, so that space travel would require some kind of safeguard against cosmic rays.

Just what the effect is can only be guessed at now. Before the

man-made satellites were put in orbit, the evidence was necessarily scanty. A United States Air Force pilot, for example, who ascended 102,000 feet in a balloon in 1957, close to the present upper limits of ascension, acquired two gray hairs on his forearm as a memento of the trip. While this may seem a trifling occurrence, photoplate evidence indicated that the pigment cells of the hairs were killed by a primary cosmic ray.

The data received so far from the satellites seems to indicate that the cosmic radiation was even more powerful than the scientists anticipated. For this reason Explorer III was equipped with only a single Geiger counter, which was jammed by the heavy radiation.

Early reports from Explorer IV indicated that it was receiving radiation 167 times more intense than was the case with Explorer III. One of the Geiger counters which was unshielded received 60 per cent more than the other one which was shielded. This indicates amazingly high radiation, a thousand times more intense than was expected.

The later analysis of the data from Explorer IV confirmed the original impression. And, since future satellites will go beyond the 1,200 mile altitude of Explorer IV, even more intense radiation can be expected.

Recent scientific speculation pictures cosmic radiation as a huge envelope that is part of the sun's corona, while another theory suggests the possible existence of a band of cosmic radiation in space, with a thickness of 40,000 miles or more. Such a band, it is said, might be dissipated by unmanned "sweeper satellites" operating like snowplows!

Scientists are still uncertain about the dangerous effects of this radiation, as it may be made up of cosmic rays containing protons, or some other kind of radiation, similar to gamma rays (page 144), containing electrons.

In the case of the latter, the rays have an intensity of 10 roentgens an hour. (The maximum safe dosage of radiation, according to the Atomic Energy Commission, is 0.3 roentgens in a week.) It is estimated that anyone exposed to such radiation for 45 hours would have a 50 per cent chance of dying within a month's time.

Radiation from protons is ten times more intense, so that exposure for four and a half hours would produce a 50 per cent chance of dying in a month's time.

Thus much of the mystery still remains. But when we see how much scientists have learned about radiation in a comparatively short time, we can feel confident that eventually cosmic rays will yield their secrets.

5. The World of Radio, Radar, Television and Ultrasonics

No other invention has been developed so rapidly as radio nor achieved so commanding a position in so short a time. As an entertainment medium, radio got its start as recently as the 1920's, and its offspring, television, has had an even shorter and more sensational career; yet most of us would find it difficult to imagine what life would be like without them. Radar, another offspring of radio, played a decisive role in World War II. In scientific work, radio astronomy has made such giant strides that it is likely to surpass the finest telescopes as a means of increasing our knowledge of space. All the valuable information that is being received from the man-made satellites is crucially dependent on radio.

Thus, while entertainment is the aspect of these devices with which we are most familiar, it is outweighed by far by the uses to which they have been applied in other fields.

ELECTROMAGNETISM

Very few of the people who listened with headphones to the first radio programs could have been aware that these programs were the end-product of a process that had started a century earlier when Hans Christian Oersted discovered that when electric current flows through a wire, the wire becomes magnetic. Oersted demonstrated that such a wire has a magnetic field by using it to make a compass needle swing away from its normal north-south position. This discovery set off a series of brilliant researches which led to the realization that electricity and magnetism were different forms of the same kind of energy.

Michael Faraday (1791–1867) and Joseph Henry (1797–1878) both discovered that if a coil of wire was wound evenly around a soft iron core, the coil had a larger magnetic field when electric

current was applied to it. The combination of a current flowing through a coil wound around an iron core is called an "electromagnet." The strength of the electromagnet will depend on the amount of current supplied; on the number of turns in the coil; and on the quality of the iron core.

James Clerk Maxwell, a disciple of Faraday, demonstrated by mathematical reasoning that electromagnetic energy (emitted by electromagnetic means) travelled in vibrating waves; that light waves were electromagnetic waves; and that all these waves travelled at the speed of light waves (186,000 miles per second). One feature of Maxwell's theory that seemed queer to his contemporaries was that it pointed to the existence of electromagnetic radiation which had longer wavelengths and lower frequencies than those of visible light. How could there be such waves if there was no evidence for their existence?

Before we see how Maxwell's theory was proved in practice, it will be helpful to turn to the practical uses to which electromagnetism was first put. It was used to power electric motors; to generate electricity from dynamos; and it made the electromagnetic telegraph and telephone possible.

THE ELECTROMAGNETIC TELEGRAPH

The first important practical use of electricity was to send messages by wire. In the Wheatstone telegraph this required the use of magnetic needles; the Morse telegraph involved transmitting "dots and dashes" — bursts of current — along a wire by means of a tapping key that also acted as a switch to open and close a circuit.

At the receiving end, an iron core with attached pencil and paper was magnetically moved by the bursts of current, causing the pencil to move on the paper and record the message.

An early difficulty of the telegraph was that after travelling 15 miles or so, the current would weaken disastrously. Joseph Henry solved the difficulty with his relay system. He linked up a whole series of circuits, each with its own electromagnet. The current from each circuit reached an electromagnet which turned on the switch of the next circuit; and in the process the signal was restored to its original strength.

The modern telegraph uses automatic devices. At the transmitting end the message is "typed" in patterns of holes that represent the letters. The patterns of holes are transformed into patterns of electrical impulses sent on a wire. At the receiving end a teleprinter reconverts the electrical impulses into the original hole-patterns and then prints the message on a ticker tape.

After the invention of the telegraph, the transmission of the human voice along an electrical wire seemed the logical development. But this presented many difficulties because the telephone calls for the transmission of sound waves as well as electrical impulses.

HOW WE HEAR

Sound is caused by vibrations. These are back-and-forth motions of objects that have been set in motion by some external force, such as a push. The motion of a clock pendulum, for example, produces vibrations. The range of sound that can be detected by the human ear extends from about 20 cycles of vibrations per second to upwards of 15,000 cycles of vibrations per second.

When molecules are set in motion by a vibration, they move in waves at a certain rate of speed. This rate is known as the frequency. When our ears feel the vibrations, the eardrums vibrate at the same frequency. From our ears, connecting nerves bring this information to the brain — and we have our sensation of hearing.

Higher tones create a greater number of frequencies; the vibrations are fast, and the wave-lengths are short. Lower tones have a smaller number of frequencies, with slow vibrations and long wave-lengths.

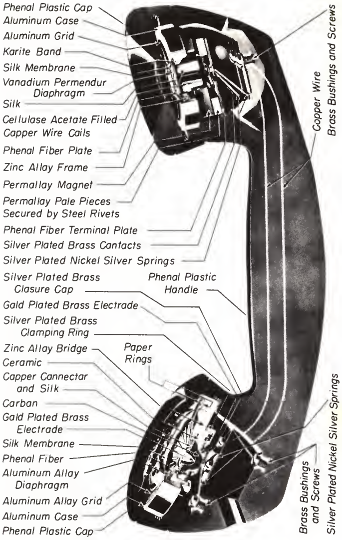
Some sounds are either too low or too high to be caught by the human ear. (We call them "ultrasonic.") Scientists can detect these soundless sound waves with the oscilloscope, which uses an electron beam to mark the path of the vibrations.

Musical instruments like the flute and the bassoon give us a perfect example of how sound is produced. The player blows into a tube. This causes the air inside the tube to vibrate. The player changes the pitch (tone) by stopping up the holes in the tube. The pitch varies according to the distance the sound travels; stopping a different hole produces a different tone.

If sound waves are allowed to spread out in all directions, the sound cannot carry very far. Consequently, to make sound travel for some distance, it is necessary to force it into a tube or some other conducting agent. (The doctor's stethoscope works on this principle of concentrating sound, so that he is able to hear the beating of a patient's heart.)

Alexander Graham Bell's idea for inventing a workable telephone was that sound waves can be converted into electromagnetic waves, carried for a distance and then reconverted into sound waves.

His telephone had a skin diaphragm stretched over the mouthpiece. Attached to this skin was a piece of iron fastened to an electromagnet



The telephone is one of the most precise and delicate instruments in everyday use. There is a world of difference between the crude working models of Alexander Graham Bell and the highly complex instrument we use today.

behind the skin. When sound waves struck the skin, they made it vibrate. The vibrating skin in turn struck the iron, which vibrated accordingly, so that electric currents passed through the electromagnet.

These currents travelled along a wire which was connected with a receiver. Here the currents struck another electromagnet, making the iron vibrate on the receiving diaphragm. These vibrations reproduced the original sound waves which had been fed into the transmitter.

The transmitter converted sound waves into electric current, while the receiver reconverted the current into the original sound waves. (This is essentially what happens in radio transmitting and receiving, though without the use of carrying wires.) However, the Bell telephone did not work too well because the electrical signals were too weak.

THE MODERN TELEPHONE

Thomas Edison soon designed a far more efficient transmitter. He used a mica mouthpiece which was connected by an ivory button to granules of powdered carbon placed between two platinum disks. As carbon is an excellent conductor of electricity, the varying impact of the sound waves on the mouthpiece was effectively reproduced by the resulting vibrations of the carbon granules.

In Edison's instrument the fluctuations of the current varied according to the pitch of the sounds that struck the mouthpiece. In addition, the flow of the current was determined by the volume of sound. If the sound was softer, the current was weaker.

After the current reached the electromagnet in the receiver, the sound waves that emerged from the metal diaphragm corresponded in loudness to the strength of the signals that had passed through the wire. Basically the telephone still operates on Edison's principles.

Most sound waves give the transmitter diaphragm a push of only 10/millionths of an inch. This moves the carbon granules a few billionths of an inch — enough to give the desired result.

More than 30 billion messages are sent in the United States during the course of a year, and over 100,000 telephone conversations are being held at any given moment.

It necessarily follows that telephone switchboards are incredibly complicated pieces of equipment. Some of them handle 10,000 wires and call for two million individual parts. No wonder there are almost 10,000 switchboard patents! Automatic devices have been brought to such a degree of skill that when anything goes wrong on a switchboard, the mechanism calls up a maintenance man and prepares a message on an electric typewriter informing him what was happening at the time the damage occurred.

In long-distance telephoning, the electromagnetic waves carrying the message tend to get weaker the farther they travel (the same difficulty that was originally encountered in the case of the telegraph). Vacuum-tube amplifiers are placed at regular intervals to strengthen the weakening energy of the waves without distorting them.

In order to maintain a conversation between San Francisco and London, it is necessary to use 256 of these amplifiers. Each one increases the preceding volume ten times. The total amplification is 10 followed by 255 zeros. Actually this results in no more than the same volume at the receiving end as prevailed at the transmitting end.

In transoceanic telephoning, radio is used instead of cables. To maintain the privacy of such conversations, the waves are electronically "scrambled" into incomprehensible noise. At the receiving end all the distortions are reversed with utmost precision and the message emerges in its original form. To rule out static, the radio part of the message is equipped with frequency modulation.

Nor does this exhaust the versatile features of the telephone. Its other uses include telephoto pictures, teletyping and network broadcasting.

HERTZ DISCOVERS RADIO WAVES

We accept the telephone as a matter of course, and take too much for granted all the wonderful ingenuity that has been lavished on it. Radio, on the other hand, still carries an aura of the miraculous about it. Sound waves travel through the air at a speed of about 1,100 feet a second. We know they are rapidly diffused if they are not concentrated in some kind of carrying container. How then can sounds be heard instantaneously at a distance?

The answer is, of course, that sound waves are fed into a radio transmitter and emerge from a radio receiver. The job of getting them from one place to the other is done by radio waves. And this brings us right back to James Clerk Maxwell's theory of electromagnetic waves.

Maxwell created a point of departure for later investigators when he concluded from his mathematical calculations that it would be possible *to produce certain kinds of electromagnetic waves by creating electromagnetic discharges.*

Heinrich Hertz was the man who demonstrated the correctness of Maxwell's theory, and the demonstration took place in 1887. For this experiment, one of the most important ever performed, Hertz used some simple equipment costing the equivalent of twenty dollars.

Hertz placed two electric coils near each other. Directing an

electric current into one coil, he saw sparks leap up in the other coil. The electric current had jumped the gap. Hertz was making the electricity travel through space, instead of in a wire, as had always been done previously.

The sparks were not continuous. They came in spurts. These were electromagnetic waves — the kind whose existence Maxwell had prophesied. By timing the sparks, Hertz could calculate the wave-lengths and the frequency of the vibrations. He called the waves "radio waves."

In later experiments Hertz made the radio waves behave in the manner of light waves. For example, he directed the radio waves against a mirror and they were reflected back. He deflected the radio waves, and they were bent — again just like light waves.

There was this difference: while the radio waves travelled at the same speed as light waves, their wave lengths were quite dissimilar. Even the shortest radio waves are much longer than light rays; and, in the case of long radio waves, some have wave-lengths of many miles.

Hertz died in 1891 at the age of 37, but his pioneering experiments contained the germ of radio transmission, radar and television.

EARLY DEVELOPMENTS

Hertz's remarkable discovery created enormous interest in the new radio waves, and new developments and improvements followed in rapid succession.

About 1890 scientists discovered that if alternating current is passed through powdered metal in a glass tube, the metal acts as an excellent conductor of the current. A receiver which picked up radio waves from the air used the oscillating principle (rapid alternation of current produced by rotating a coil of wire between the poles of an electro-magnet).

When radio waves were emitted in short bursts by a transmitter, the signals could be picked up by the receiver. The Morse code of dots and dashes proved ideal for sending and receiving messages. By 1894 Sir Oliver Lodge, applying these principles, was able to transmit messages by "wireless" for a distance of half a mile.

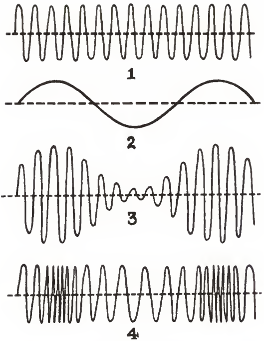
At first the signals were quite feeble, but a Russian named Popoff, who was professor of physics at the Kronstadt Military Institute, introduced the receiving antenna. Guglielmo Marconi then added the transmitting antenna, and the combination enormously strengthened the signals and substantially increased the distance over which they could be transmitted.

The transistor, which has made possible the miniaturization of radio, computer and other electronic equipment, is so tiny that it is no larger than a fly's eye. Transistors are made of germanium, and in order to function properly they require impurities of no more than 1 in 10,000,000.

By 1896 Marconi had improved his equipment sufficiently to be able to send messages for two miles. An aerial attached to the receiver picked up the electromagnetic waves sent out by the transmitter. After passing through the aerial wire the signals flowed into the receiver and moved a telegraph key which reproduced the "dots and dashes."

In 1898 Marconi transmitted signals across the English Channel, and before the end of the nineteenth century the first SOS signals were sent out from a ship in distress off the English coast. The installation of radio equipment on vessels dates from this time. In 1901 Marconi succeeded in transmitting the first transatlantic signals, and the race was on to make the most of the commercial bonanza that radio represented.

The invention of the vacuum tube for radio, which was discovered independently in the United States and England, was another mile-



The chart illustrates different kinds of radio waves. (1) is the carrier wave along which the signal wave (2) is conveyed. Wave (4) shows the effect of frequency modulation. The height of these waves remains constant while the distance between them varies. In the AM waves (3), the distance between the waves remains constant, while the height (amplitude) varies.

stone in the development of radio. A radio concert was broadcast as early as 1906 by Professor R. A. Fessenden at his experimental station at Brant Rock on the Massachusetts coast. It was heard as far away as Virginia. Nevertheless, the development of radio as an entertainment medium had to be deferred for a good many years, partly because numerous technical improvements had to be made, and partly because the possibilities were not immediately obvious.

The terrible disaster when the *Titanic* sank in 1912, and 1,500 passengers lost their lives, dramatically focussed popular attention on radio. About 700 passengers were saved through the SOS calls sent out by the radio operator, and more might have been saved if the messages had been answered more promptly. (As a matter of fact, if radar had been available then, the presence of the hidden iceberg which wrecked the great liner would have been detected in good time.)

RADIO WAVES

Radio waves can be divided into two broad categories: long wave (low-frequency) and short wave (high-frequency). Long waves are reserved for broadcasting stations, while short waves, reaching down into the microwave range, are parceled out for various uses, including television, communications, police calls, transoceanic broadcasting, radar, amateur signals, etc.

Long waves leave the transmitter at the rate of anywhere from 550,000 cycles (550 kilocycles) to 1,500,000 cycles (1,500 kilocycles) a second. This is the standard broadcast band of frequencies, although some stations may operate at slightly higher than 1,500 kilocycles. (A cycle is the complete back-and-forth vibration of a wave.)

The wave-length which corresponds to 550 kilocycles is 545.1 meters; the wave-length which corresponds to 1,500 kilocycles is 199.9 meters. The tuning dial of the ordinary radio set is calibrated for frequencies of from 550 kilocycles to about 1600.

AM AND FM

The electrical signals that leave the microphone are too weak for broadcasting purposes. They are therefore combined with carrier waves. This strengthening of the signals is called "amplitude modulation." Amplitude is the distance from the top to the bottom of the wave. Modulation refers to the constant change in the amplitude of the radio wave. Louder sounds increase the amplitude; softer sounds decrease the amplitude. Higher notes increase the frequency; lower notes decrease the frequency.

At the point of shortest amplitude, the electric waves that are being transmitted are exposed to contact with static electricity. This produces disturbances that are picked up in the receiver.

In the case of frequency modulation, changes in loudness and pitch cause variations in the frequency, but the amplitude of the radio wave remains constant. The electric wave remains inside the radio wave and is thus almost completely shielded from contact with static.

There is still another difference between amplitude modulation (AM) and frequency modulation (FM). Amplitude modulation operates at about 10,000 cycles, but the human ear can take in a wider range — frequencies of upwards of 15,000 cycles per second. Frequency modulation reproduces all the sounds audible to the human ear. FM sound is therefore superior to AM on two grounds: absence of static, and wider, more faithful reproduction of "highs."

But frequency modulation has drawbacks, too. FM waves, like light waves, travel more or less in a straight line and cannot be heard

below the horizon. The other difficulty is that FM tuners tend to "drift" away from the frequency selected for reception. The more expensive FM receivers have a device to "lock" in the frequency and prevent drift.

HOW RADIO WAVES ARE TRANSMITTED

If two or more stations were to broadcast on the same frequency, a radio receiver tuned to that frequency would merely emit a jumble of confused sounds. Consequently each station is allotted its unique frequency ("channel").

The oscillating vacuum tube (or valve) used for transmitting operates in conjunction with a special crystal. These crystals have the property of emitting vibrations when energy is supplied to them. The thickness of the crystal will determine the wave-length of the vibrations. Thus, when the proper crystal is used, it will cause the radio waves transmitted by the oscillator tube to vibrate at the desired frequency.

The microphone picks up the sound waves produced in the broadcasting studio and converts them into electrical waves. The converted waves pass to the control room, where audio-frequency tubes amplify them as much as 30 trillion times on their way to the transmitter.

Where the broadcasting is done by a network, the amplified signals are sent by long-distance telephone to local stations. Then each station sends out the waves from its own transmitter.

The broadcasting antenna picks up the electrical waves from the transmitter, and by the action of alternating current, forces the waves out into the air. Most of the waves ascend to the ionosphere, the topmost layer of the earth's atmosphere. From here the waves are reflected back to the earth, ready to be picked up by radio receivers.

HOW RADIO WAVES ARE RECEIVED

A radio receiver has to perform certain functions: it picks up the radio signals; converts the high-frequency alternating-current radio wave into low-frequency direct current; and finally reconverts the electrical waves into sound waves that are audible to our ears.

The aerial and ground connection pick up the modulated radio waves and send the signals into the receiver. With waves of all kinds of frequencies arriving, the receiver must be equipped with a device for selecting a desired frequency. This is accomplished with an inductive coil and a condenser manipulated by a tuning dial or knob.

The process of selecting a continuous set of waves at a specific frequency is called "tuning." The condenser is made up of metal plates

The technician is tuning the radio receiver to obtain information from the transmitting instruments of a radiosonde—a balloon equipped with instruments to assemble information about the weather. As the information is received, it is tabulated on a record sheet.

separated by air spaces. As the dial turns, it causes the condenser plates to revolve. Each new position of the condenser plates yields a different frequency. The numerals on the tuning dial are calibrated to create a permanent relationship between it and any given frequency.

The conversion of the radio waves from high-frequency alternating current to low-frequency direct current is done by vacuum tubes. Other vacuum tubes have the job of amplifying the signals; a power tube supplies current to the loud-speaker. Here the signals pass through an electromagnet and cause a cone to vibrate. This converts the hitherto inaudible radio waves into sound waves that can be heard by the human ear.

RADIO COMMUNICATIONS

Radio has many other uses aside from broadcasting, especially in the field of communications. Radiotelephony has been introduced in many parts of the world, making it possible to carry on transoceanic conversations directly. The principle has been applied to the "walkie-talkie" and to communications of radio personnel. Two-way radio has made airplane landings and flights much safer and more efficient. In addition, pilots find radio beams and the radio compass valuable guides to navigation.

Turnpike systems use very-high frequencies and microwaves for communications between police cars, service trucks, toll stations, administrative vehicles and maintenance areas.

A world-wide communications network has developed for the transmission of individual radio messages ("radiograms"). It is even possible to transmit photographs by radio. In this "radiophoto" process, a picture is placed on a slowly revolving drum which is exposed to a photoelectric cell. This picks up the photo as a combination of white and dark light waves, and the current is converted into radio waves.

The receiver gets the radio signals and converts them into light waves which are projected onto sensitized paper on another revolving drum. This projection reproduces the original picture. The interval required for transmission of the picture is incredibly brief.

RADIO USES IN MEDICINE

The most familiar medical use of radio waves is in the field of diathermy — a method of heating internal parts of the body which cannot be reached in any other way. The treatment is used extensively to reduce inflammation and to ease the pain of such ailments as neuralgia, neuritis and bursitis. Though high voltages are required with this kind of therapy, it is quite safe when proper precautions are taken.

Just how the waves achieve their effect is not known, for there is still much to be learned about the way that molecules of the body are affected by strong magnetic fields.

An unfortunate result of the use of diathermy machines is the troublesome jamming they sometimes cause in the frequencies used for radio communication. In 1947 the Federal Commerce Commission issued a ruling that limited diathermy machines to two frequencies: 27.12 megacycles and 13.56 megacycles. Current owners of equipment were given until 1953 to comply with the regulation. It is estimated that as late as 1957 10,000 machines were still being operated at illegal frequencies, jamming the short-wave frequencies.

The Rockefeller Institute for Medical Research has developed a "radio pill" which is an inch long and 2/5ths of an inch in diameter. This pill, which contains a miniature FM radio transmitter enclosed in a capsule, will make examination of internal parts of the body much more efficient.

As the pill passes through the digestive tract and the gastrointestinal tract, it transmits radio signals to an FM radio receiver placed near the patient. In its present stage the pill offers important information about chemical disorders and localized inflammations. It is being improved to provide valuable information about the digestive tract.

Microwave energy can be used to apply heat therapy with simplicity and safety. The equipment required is far less complicated than that used in diathermy.

In surgery, the radio knife operates with high-frequency current. It is particularly suitable for brain operations, as it creates no pressure on tissues, coagulates the capillaries and thus prevents bleeding.

OTHER USES FOR RADIO

High-frequency waves are ideal for many kinds of electronic inspection. Plants and factories pass their finished products through an electromagnetic field which scans the packaged products for hidden flaws.

Weather forecasting has benefited by the use of radiosondes. Instruments are attached to a balloon which is sent up into the atmos-

phere to report back by radio on weather conditions above the earth. This technique has been applied to the artificial satellites first launched in 1957 (see page 97).

RADIO ASTRONOMY

Astronomy is the oldest of the sciences, with evidences of it being found in the remains of man's oldest civilizations. But one branch, radio astronomy, is the youngest of all the sciences. Pursued intensively only since 1948, it is well on the way toward becoming the most important branch of astronomy.

It began in 1932 when Karl Jansky, a Bell Laboratories engineer, was engaged in research on the causes of static that was interfering with transatlantic radio-telephone reception. He soon noticed a persistent kind of noise that he described as "very weak . . . very steady, causing a hiss in the phones."

Jansky considered the possible causes — nearby power lines, disturbances originating in the earth's atmosphere, interference from radio transmitters. Further study showed that none of these were responsible for the hissing static. During the day the source of the hiss seemed to move from east to west. At night it faded out. The next day it resumed from its previous position.

Could the noise be coming from the sun? Finally, careful calculations with the aid of his directional receiver led Jansky to conclude that the hissing static originated in the Milky Way, the galaxy that contains our sun, and billions of other stars.

During World War II, accidental discoveries revealed that the sun is also a source of radio waves. A sun spot has been described as a tremendously powerful transmitter of ultra-short waves. The power is in the neighborhood of one million kilowatts. What puzzles scientists is that the solar radio-noise intensity is over a million times greater than it ought to be on the basis of previous calculations.

THE AURORA BOREALIS

Brilliant "northern lights" have baffled scientists for centuries. These lights are centered on the earth's northern magnetic pole. The southern counterpart of these lights, the aurora australis, is thought to be centered on the southern magnetic pole.

(On next page) Radio telescopes have characteristically huge "dishpan" antennas in order to get reception from stars that are billions of light-years away. Some of these signals are so faint that they have 1/10,000th of the intensity of signals on an ordinary radio receiver.

After measuring the wave-lengths of the aurora and studying the lights by means of the spectroscope, scientists decided that the lights originated from oxygen and nitrogen atoms that give off electrons in the atmosphere.

Further investigation has shown that the intensity of the aurora fluctuates through an eleven-year cycle that parallels the sun-spot cycle. The two seem to be connected, and when their activity is at its highest, the amount of radio static increases considerably, often making good reception a hopeless task.

Scientists believe that the electrically charged particles that are shot out from the sun cause the aurora phenomenon. When these particles reach the ionosphere, they break up oxygen and nitrogen atoms. The brilliant light that is emitted by these reactions makes up the aurora borealis.

Ingenious theorists have suggested that some day we might produce artificial illumination by bombarding the ionosphere with radio waves, producing a man-made aurora borealis. In 1952 this was done on a miniature scale in a University of Chicago laboratory. Bombardment of the air with hydrogen and alpha particles (page 144) from an atom-smashing machine resulted in a greenish-blue light.

RADIO TELESCOPES

To receive radio signals from stars that are billions of light-years away, radio astronomers have to use very powerful receivers and the largest practicable antennas. Some of these antennas are so sensitive that they can pick up signals that are 10,000 times weaker than the signals picked up by home receivers.

Just as light rays are collected by a paraboloid mirror, the radio waves are collected by a special paraboloid ("dish-shaped") antenna. The waves are then focussed and fed into the receiver.

The power of radio telescopes to reach out into space is being considerably strengthened by "MASER" (microwave amplification by stimulated emission of radiation). Both the Harvard Laboratory and the U. S. Naval Research Laboratory have done valuable work on MASER.

Briefly, this is the principle involved: MASER operates with a cheap crystal which steps up the feeble radio signals from space by adding its own radiation at the same wave-length. (The Naval Research Laboratory uses a synthetic ruby which costs a few cents.) In time, scientists hope to increase the sensitivity of radio telescopes a hundred-fold.

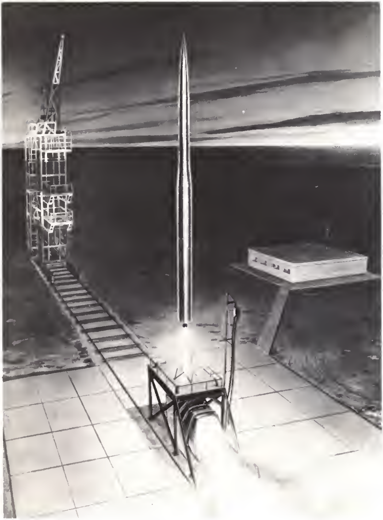
Today there are dozens of powerful radio telescopes all over the

An artist's conception of the transmission of a radar signal from the earth to the moon and the returning echo of the signal. This was first done in 1946 and took 2.5 seconds.

world. The largest is the one at Jodrell Bank in England. Its paraboloid antenna, 250 feet in diameter, is mounted on rockers 180 feet high, and rotates on a 360-foot circle of railroad tracks.

"COSMIC NOISE"

It is comparatively easy to distinguish signals from the sun, because its distance of 93 million miles is relatively short as interstellar distances go. The impression of the sun obtained from radio waves is different from the visual impression. For one thing, much solar radiation is invisible and therefore escapes our attention. But radio waves bring us a report of the invisible radiation.



Artist's conception of the three-stage launching rocket used to place an artificial satellite in orbit. The data sent back by radio transmitters in the satellites has provided a great deal of valuable information for radio astronomers.

Radio bursts from the sun were first noticed by radar operators during the Battle of Britain in 1942. They found that reception was jammed from time to time so that they could not follow the course of enemy planes. When this interference was investigated, it was found to come from the sun.

Another fruitful phase of radio astronomy has been the study of great hydrogen clouds in which the atoms are so thinly diffused that by terrestrial standards these clouds would be considered a vacuum. The importance of these studies is emphasized by the fact that hydrogen atoms are thought to make up 93 per cent of the atoms in the universe. The atoms in the hydrogen clouds absorb and broadcast radio waves with a wave-length of 21 centimeters.

Radio astronomy also increases our knowledge of stars that have exploded with unimaginable violence — "novae." Cosmic dust clouds, which conceal light from visual telescopes, offer no difficulty to radio telescopes.

Even more startling are the radio studies of the colliding Cygnus galaxies, each containing tens of billions of stars. The curious thing is that a galaxy contains so much empty space that ordinarily two galaxies can pass through each other without any contact. But in the case of Cygnus the trailing clouds of hydrogen are so enormous that a collision became inevitable. With the atoms moving at velocities of 6,000 miles per second, so much energy was released that radio signals reached the earth, though the galaxies are 270 million light-years away.

The wattage at which such releases of energy operate is calculated to be 1 followed by 36 zeros. Scientists have conjectured that this implies the effect of vast interstellar electromagnetic fields on atomic particles. If radio astronomy can discover the principle involved, it may be of decisive value when applied to the use of powerful man-made magnetic fields in fusing hydrogen atoms (page 190).

No less remarkable is the radiation reaching the earth from the Crab Nebula, now a hazy luminous spot in the heavens but once a star that exploded in 1054 A.D. (The date is known to us from astronomical records of the time.) The radiation emanating from this star gives evidence of being the same kind as is released in the great synchrotrons with the aid of enormous electromagnets. Radio astronomers are baffled in trying to account for the source of the incredibly powerful magnetic field that made this radiation possible.

RADIO AND THE SATELLITES

One of the most important results of propelling artificial satellites into space is the vast increase in information that is being supplied

to radio astronomers. They expect, for example, to get a much clearer idea of how events on the sun affect the radio properties of our atmosphere. Using instruments that are placed in satellites, they hope to measure the heat reflected by clouds, snow and moisture and radiated into space by the earth and its atmosphere.

The journey of a U. S. satellite in its orbit is tracked by a radio system known as "Minitrack." The readings of a satellite's position are obtained by an electronic circuit from the periodic signals sent by the satellite's transmitter. This whole system is part of the Vanguard project. Eleven stations are used — some on the west coast of South America and the east coast of North America, and the rest in various parts of the world.

The satellite instruments supply data on a one-pound tape recorder and radio it every 30 seconds. Whenever a satellite passes a recording station, it receives an electronic command to broadcast its information, after which new material is stored on the recorder. The information comes in the form of mathematical equations, which reach a total of about 230,000 in three months.

All observations picked up by Minitrack stations are teletyped to a central electronic computer which calculates the orbit, making allowances for such distortions as the bending of the radio signal when it passes through the ionosphere, and the wobbling of the orbit caused by the bulge of the Equator.

BYPASSING THE ATMOSPHERE

Scientists have divided the atmosphere into: (1) the troposphere (nearest to the earth), containing 80 per cent by weight of the atmosphere's air; with increasing altitude, temperatures decrease steadily to about –67 degrees Fahrenheit; (2) the tropopause, a thin layer which leads into (3) the stratosphere, which has gentle winds and rising temperatures; this includes the ozone layer, where ultraviolet radiation from the sun is filtered out; and (4) the ionosphere, where radio waves from the earth are reflected back to the earth; temperatures rise steadily here, possibly to 500 degrees.

Despite intensive study in the past, there still remains much to be learned about the atmosphere. In the case of the ionosphere, for example, recent observations have yielded puzzling results. The altitude generally assigned to this layer of the atmosphere has been from about 50 miles above the earth to 200 or so miles up. But recent radio findings indicate that the ionosphere may extend anywhere from 6,000 to 20,000 miles out into space.

This is one of the many subjects that are expected to yield their

secrets as man extends his gingerly initial probing into space. The chief obstacle to his acquiring more exact astronomical knowledge has been the atmosphere, which has greatly hampered the effectiveness of even the finest visual telescopes. As satellites are sent into progressively larger orbits and when navigating spaceships becomes feasible, man will acquire a knowledge of the universe which for the first time in his history will not be distorted or obscured by the atmosphere.

Here are some of the most exciting prospects that will be opened up to astronomical research:

Further study of the radio waves emanating from the sun may yield far more accurate weather forecasting than we have had up to the present. Airplane navigation may be tremendously improved by the "solar sextants" on which U. S. Navy and Air Force scientists are working. Steering would then be guided by solar "broadcasts."

Study of the planets would make enormous progress. Venus, for example, is the closest of the planets, yet we know less about it than about any other planet because it is enveloped in clouds. If infrared or ultraviolet rays could be sent to this planet from a satellite beyond the earth's atmosphere, we would find out a great deal more about Venus.

As a matter of fact, the study of Venus by radio astronomers has already provided a good example of the way in which their work can correct errors in the findings made with optical telescopes. The temperature assigned to Venus was based on observation of the light it emitted; but since this light is partly obscured by the planet's atmosphere, the calculation of the temperature was incorrect. The radio signals showed that the temperature of Venus is actually twice as high as had previously been thought.

Similarly, satellite observation of Mars would give us a definite notion of whether there is any vegetation on Mars. At present most of the radiation from this planet is lost in the earth's atmosphere.

With the use of visual telescopes, it has been impossible to calculate the diameter, density and composition of Mercury, the smallest planet. Here again the earth's atmosphere has been the stumbling-block. These problems could be solved by the newer methods.

The planet Jupiter sends out radio signals that are calculated to have 100,000 times the power of a strong lightning discharge on our own planet. Yet we still know very little about the atmosphere of Jupiter, or its surface. Satellite observation can be helpful here.

Other possibilities that suggest themselves are a much clearer scrutiny of gamma and X-radiation throughout the universe. Many sections of the Milky Way now closed to us will become available for study for the first time. Whereas the giant Palomar telescope reaches

out 2 billion light-years into space, starting from beyond the earth's atmosphere might make it possible to extend this range 4 billion light-years and more. In that case we might even get a clear notion of how the universe was formed!

These, then, are some of the indications that man stands on the brink of some of the most remarkable discoveries in the whole range of scientific observation.

THE EARLY STORY OF RADAR

More than one German writer has attributed his country's defeat in World War II to Britain's superb use of radar and Germany's neglect of this formidable weapon. What makes these developments even more ironic is that a German discovered the underlying principle of radar and another German invented the first radar device.

Heinrich Hertz had shown back in 1887 that radio waves, like light waves, could be reflected from a mirror so that they would bounce back with an "echo" that could be registered on an instrument.

As early as 1904 Christian Huelsmeyer, a Duesseldorf engineer, patented a device which he called a "telemobiloscope." He demonstrated successfully that it could inform an observer of the location of distant metallic objects, operating with audible or visible signals.

Science-conscious though the Germans were, they showed no interest in Huelsmeyer's invention and he died a forgotten man. Even the *Titanic* disaster could not rouse the Germans from their indifference, for at that time no one dreamed that the crude radar equipment of the period could be improved to reflect masses of snow and ice.

In 1923 an American named Heinrich Lowy patented a similar radar device in the United States. His timing was bad, for the enormous interest in radio as entertainment, just getting its start at that time, condemned his invention to fatal neglect.

Yet only two years later, the first practical test of radar took place in the United States. Working with rudimentary equipment, scientists at the Carnegie Institution measured the distance from the earth to the ionosphere. From then on, American scientists continued to work on radar, though of course not with the same concentration and sharp sense of urgency that was soon to dominate British radar research.

In the 1930's the Germans at last pursued radar research in a rather half-hearted fashion. However, the Germans were intent on a crushing *Blitzkrieg,* and saw little need to divert their energies to what they considered a defensive weapon.

The attitude of the British was quite different, as they watched World War II draw near. Being outnumbered in men and weapons,

The dishpan antennas of a radar scanning system are the basis of warning systems used to signal the approach of enemy aircraft.

they were desperately in need of a first-class warning system against air raids.

Sir Edward Appleton, a famous authority on the earth's atmosphere, had demonstrated the existence of layers in the atmosphere. He had sent radio signals to the atmosphere and noted the elapsed time between transmission of a signal and the reception of its echo.

RADAR COMES OF AGE

All of this seemed rather remote from the pressing needs of the hour. It was only when Sir Robert Watson Watt, another leading British scientist, showed that the echo could be projected on a fluorescent screen by the use of a cathode-ray tube, that the value of radar was at last revealed.

On such a screen ("oscilloscope" or "scope" for short), it became possible to follow the course of a distant object — such as a hostile bombing plane. A directional antenna shows where the plane is coming from, and the elapsed time for the "blip" or return of the echo, indicates the distance of the object. To realize the potentialities of radar still required an enormous amount of research.

Radar research was now entrusted to a committee of outstanding scientists in Great Britain which carried out its far-reaching activities with utmost secrecy. The first practical radar test in England took place in 1935, when an approaching plane was satisfactorily detected at a distance of about six miles. This was immediately followed by a decision to build coastal radar stations.

Radar training in the RAF started in 1937. By July 1939, two months before the outbreak of World War II, it was possible to detect the approach of an airplane at a distance of 60 miles. Meanwhile German observers had seen the new radar stations and wondered what they were used for. Their spies reported that the stations were operating at wave-lengths that were too long for the most effective radar work. (For reasons that will be explained on page 110, radar gives the best results when used with microwaves — the shortest wave-lengths in the radio-wave band.)

So for a while the Germans were content. What they did not know was that the British were using the longer wave-length to deceive them, and had already made the necessary preparations for switching to a much lower wave-length.

To make absolutely sure of their ground, the Germans sent the dirigible *Graf Zeppelin* on a reconnoitering expedition along the British coast on August 2, 1939, only a month before their invasion of Poland. A full complement of technicians went along in order to pick up British radar signals.

But, after trying every conceivable wave-length on their receivers, the Germans could not detect a single suspicious signal. Now the Germans were really satisfied — so much so that they did not bother to perfect their radar-jamming systems. What the men on the *Graf Zeppelin* did not know was that as soon as their approach was detected by British radar, an order went out for complete radar silence. That

The Talos guided missile is aimed and fired by a formidable array of radar equipment. Since World War II these weapons have been continually improved in range and effectiveness.

was why they heard no suspicious signals, and why the superb efficiency of British radar took them by surprise later on.

THE BATTLE OF BRITAIN AND AFTER

The early "phony-war" phase of the war gave the British valuable time to prepare for the coming ordeal of night-after-night bombing raids. They used the interval to make constant improvements and additions to their radar defenses, and to train more radar personnel.

The endurance of the British under fire and the gallantry of the RAF in facing almost hopeless odds made an unforgettable impression; but without radar their resistance would truly have been hopeless. Shortly before the air invasion started, the British had improved their radar until they could get a radar signal of German bombers taking off near Hamburg. The state of the weather naturally had no effect on detection efficiency.

At least of equal importance was the "panorama system" of airborne radar which gave a fighter pilot a radar view in all directions and at the same time distinguished between friend and foe. This was IFF ("Identification of Friend or Foe"). Allied planes and ships carried a transmitter which automatically answered radar beams with a signal indicating the presence of a friendly unit.

Fighter planes also used airborne radar systems for automatically firing their guns. The "firefly" (image on the radar screen) would grow larger and larger as the pilot maneuvered for the best position of attack. When the firefly was big enough to touch two vertical lines on the screen (signifying that the dead-center position was reached), the guns would open fire on the target. It was also possible to operate the guns by hand.

In September 1940 Great Britain and the United States pooled their radar knowledge and research. Thousands of scientists and eventually billions of dollars went into radar. When the Japanese air fleet was nearing Pearl Harbor, radar detected it 130 miles away. Competent interpretation of the signals would have deprived the attack of its devastating surprise value.

Even in the darkest days of the German air raids, the British were forming their plans for returning the visits. In preparation for making their own bombing raids, they had developed a radio directional beam that enabled British bombers to fly "blind" at a specific rate of speed and drop their bombs when the chief of operations in England pressed a button on his desk.

The first such raid, on the great Krupp works at Essen, was carried out shortly before Christmas in 1942. The following night the bombers returned to resume where they had left off the night before. From then on, the radar-directed raids were steadily stepped up in intensity and destructiveness. These massive raids culminated in the 3,000-bomber attack which razed Hamburg in July 1944.

What made these attacks even more terrible was that the German anti-aircraft fire was not radar-controlled, so that the great bombers had things pretty much their way. The British, on the other hand, had perfected this valuable weapon of defense against air attack.

To cause a land-based gun to fire automatically at a plane caught in the gun's radar beam is not enough. By the time the "flak" hits its destination, the plane will be somewhere else. Hence this type of radar includes an electronic "gun director" which takes care of such factors as air density, temperature and wind velocity.

Above all, once the plane's speed is determined, a dial is set electronically on the director so that as shells are fired, their paths will

automatically intersect the projected course of the target plane. It is said that radar-equipped anti-aircraft brought down over three-quarters of the German "buzz-bombs" fired at British territory.

Later on there was a further refinement — the use of the proximity fuse in anti-aircraft shells. The fuse is radar-controlled to detonate a powerful explosive when the shell reaches the vicinity of the target. Radar-guided missiles also use the proximity fuse.

Anti-aircraft weapons have steadily become more efficient. The 1953 American model of this equipment, known as the "Sky-sweeper," was equipped with 315 tubes. It was designed to detect enemy aircraft at a distance of 15 miles and start firing 45 75-mm. shells a minute when the plane came within a four-mile range.

At present the SAGE (Semi-Automatic Ground Environment Control) system for defending the United States against air attack makes use of radar stations with computing centers at strategic locations throughout the country. In September 1958 the new Bomarc radar-controlled long-range interceptor missile destroyed a 1,000-mile-an-hour target missile flying 75 miles away at an altitude of 48,000 feet.

As early as 1941 the British started to use radar equipment to detect the presence of German submarines when they surfaced to recharge their batteries. Once radar was available, the darkness of nighttime was no longer a protection for the surfacing submarines. Convoys found radar valuable not only for detecting submarines but also for avoiding collisions, as the location and course of each vessel could be traced.

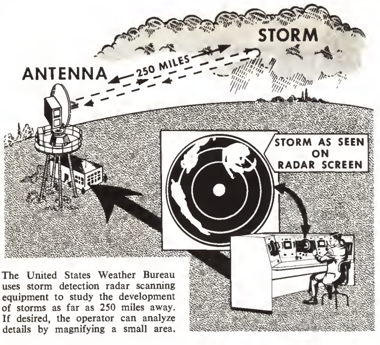
JAMMING TECHNIQUES

There was a pitiable contrast in World War II between German backwardness and Allied resourcefulness in developing radar-jamming and anti-jamming techniques. This further emphasized the air superiority which the Allied forces eventually obtained.

In 1942 the Allies introduced "Window," the code name for thin strips of metal foil which were dropped in bundles by Allied bombers as they came in for a raid. They created so many echoes in German radar receivers that detection of the bombers was seriously hampered.

The 1943 innovation was "Carpet," a technique of broadcasting "noise" from bomber-borne transmitters. Each signal was tuned to a slightly different frequency. This torrent of "noise" produced a widespread "rippling grass" pattern on the enemy's radar scopes.

In 1944 the British opened a 50,000-watt jamming transmitter in England. When German night-fighters pursued RAF formations back to the island, this station, nicknamed "Tuba," sent out powerful signals that rendered the pursuers' airborne radar useless.



The United States Weather Bureau uses storm detection radar scanning equipment to study the development of storms as far as 250 miles away. If desired, the operator can analyze details by magnifying a small area.

Today these techniques have reached new levels of refinement. When bombers near a target they transmit a countersignal on the frequency used by the defenders' radar. This obscures the echo on the ground radar scope, so that it is impossible to tell the number, direction and location of the bombers.

Despite these complications, the United States has constructed a costly 3,000-mile string of radar stations in desolate arctic regions in order to have warning signals of air attacks that might come from the North. This is the DEW Line ("Distant Early Warning Line"). In the event of attack, the radar signals would give United States industrial centers four to six hours' warning.

Many of the details are classified, but it is known that the radar scopes do not have to be manned. "Blips" indicating unidentified planes will cause an automatic alert to be sounded by electronic means.

Another important feature of this radar system is that it operates with enormous sources of electrical power — partly to overcome inter-

ference from the northern lights and arctic storms, partly to frustrate any attempts to jam the radar signals.

HOW RADAR WORKS

Notice the word "radar." It reads the same spelled from right to left. This subtly conveys the motion of the radiating signal and the returning echo. "Radar" stands for "radio detection and ranging."

It is one of the great virtues of radar that since it operates with invisible radiation, it penetrates right through darkness, cloudiness or fog.

The heart of any radar installation is the cathode-ray tube which has a large, flat, round face at one end that is called a "screen" or "scope." It is to radar what the picture tube is to television. The scope is coated with a phosphor which lights up when it is hit by cathode rays (an electron beam).

The radar scope is calibrated in microseconds (millionths of a second). Electromagnetic waves travel 984 feet per microsecond (based on the standard rate of 186,000 miles per second). Multiplying this figure by the time it takes for a signal to bounce back gives the distance of the objective. Wartime radar was so efficient that in a five-mile distance the maximum error was a few yards.

The other essential items of a radar set are the transmitter, the receiver and the antenna. The transmitter and receiver work alternately. When one is in operation, the other is not functioning. (The reason for this will soon become clear.) The alternations take place with incredible rapidity — within microseconds.

The transmitter sends out bursts of electricity which are very short — perhaps a microsecond. Between each two bursts there is a much longer interval — say 1,000 microseconds. Such an interval is good for a range of about 90 miles. Longer range would require a longer interval between bursts.

The intervals have to be much longer than the bursts because time has to be allowed for the signal to travel, strike an object, and be reflected on the receiver. Take the figures given in the previous paragraph. Suppose a radar signal strikes an object approximately 45 miles away. At the rate of 984 feet per microsecond, it takes about 250 microseconds for this to happen, and another 250 microseconds for the reflected echo to return. Total time, 500 microseconds, is well below the length of the interval between bursts from the transmitter.

During this interval between bursts it is of course the receiver that is in operation. (If the transmitter were also working at the same time, it would drown out the reception of any reflected echo.)

There are two chief systems for indicating location on the radar scope. One is called the "A-scope" beam. It scans the screen (in the manner familiar to us from television), beginning at the left when an electrical pulse is transmitted. It keeps moving from left to right. When an echo is received, it deflects the beam so that the location is properly indicated on the screen. (The distance will be clear from the calibrated scale of microseconds and the number of microseconds it took the signal to travel out and back.)

On a radio panel, tuning is arranged so that the sound is loudest when the tuning is most sharply focussed. The radar antenna's direction-finding works in the same way: when the antenna points directly at the target, the resulting echo will be at its strongest and the image on the screen at its clearest.

The other system is known as PPI ("Plan Position Indicator"). In this case the scanning of the electron beam starts in the center of the screen and moves outward in the direction the antenna is pointing. As the antenna slowly rotates, the electron beam's direction of scanning changes accordingly.

In PPI location, the electron beam is not deflected by an echo. Instead, echoes are indicated by variations in the intensity of the light on the screen. A powerful echo will result in a bright patch of light. A weak echo yields a dim patch of light. The absence of echo results in a dark screen.

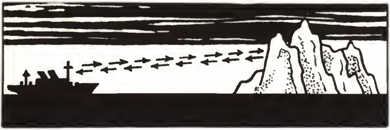
During the war, PPI was used by warships to detect the presence of hostile craft within a radius of 30 miles. It was also used in combination with gun-firing computers to assure accurate anti-aircraft fire.

Radar antennas are usually of the paraboloid "dishpan" variety. Whereas in radio broadcasting the signals are sent out in all directions, all the radar signals sent out within a certain time should be in one direction. (This focusses the radar beam most sharply.) Yet the antenna must rotate — rather slowly — so that every part of the sky is covered.

In addition, allowances in the antenna direction must be made for the pitching of a ship or the dips and wobbles of a plane. The antenna movement must also be synchronized with the cycle of transmission and reception of signals, so that the echo will come back from the same direction in which the signal was sent. To make the antenna even more sensitive and accurate, it is equipped with a reflector which focusses the radio beams very sharply.

To ensure accurate detection, it is desirable that the reflector be as large as possible in proportion to the wave-length used. A fairly long wave-length would require an impractically large reflector. It is

This vivid radar scope image of a portion of the East River in New York gives an impressive notion of the accuracy with which radar pinpoints any given locality.



Nowadays ships are able to detect unseen dangers (in this case, icebergs) by means of radar. Radar is particularly useful when the weather is stormy, foggy or misty. Submerged icebergs can be detected by using sonar.

more practical to use a reasonably sized reflector and preserve the proper proportion by operating with extremely short wave-lengths — the microwaves. During World War II, radar operated very efficiently on wave-lengths of 3 centimeters (a little over an inch) or even less.

Another way to explain the need for using the microwaves is to recall what happens in the microscope (page 54). The shorter the wave-length of the light-source, the better definition of the image.

Incidentally, even the shortest waves in the radar band are relatively enormous when compared to the wave-lengths at the other end of the electromagnetic spectrum (page 29). Thus, a typical radar wave-length of 3 centimeters is 1/10,000th of a typical standard radio wave-length of say 300 meters.* But a radar wave-length of 3 centimeters is relatively enormous in comparison to cosmic-ray wave-lengths on the order of 0.0000000000005 inches.

PEACETIME RADAR

Most of the radar techniques developed for military use during World War II were readily adapted for peacetime use. In fact, the phenomenal development of commercial aviation since the end of the war would have been impossible without numerous applications of the radar principle.

PPI has proved invaluable to vessels in rain, fog or mist, as the position of shoreline, rocks, other ships, etc. is clearly revealed on the radar scope. In the case of the collision of the *Stockholm* and the *Andrea Doria* in 1956, court testimony revealed that each vessel's radar had clearly revealed the presence of the other. Through incompetence or ignorance, this knowledge was not acted upon.

* A meter is 39.37 inches; a centimeter is .3937 inches.

Another wartime radar innovation was GCA ("Ground-controlled Approach"), later introduced into peacetime operation and used with sensational success at the time of the Berlin Airlift in 1948 and 1949.

GCA was first used for blind landings when the weather was very bad or when it was not feasible to light up the airfield. The radar operator on the ground, observing the plane as a dot on his radar screen, could guide the pilot to a safe landing by the use of two-way radio.

By the time of the Berlin airlift it was possible to pick out an arriving plane on the radar screen from a distance of 100 miles. The pilot then received instructions in stages — first from a surveillance radar operator, then from an approach man, and finally from a landing man. In time this directional system will operate on a basis of complete automation, with the radar scope at the airport communicating with an "automatic pilot" in the approaching plane.

Radar is used to good effect in short-range navigation too. To guide planes between airports, transmitters send out a beam in all directions, using high frequencies that range from 108 to 122 megacycles. This is called VOR ("Very-high Frequency Omnirange"), and it enables a pilot to fly blind, as the position of the beam on his radar scope tells him whether he is on course or off.

The high-frequency waves are blocked by the curve of the earth; consequently, the range at which the plane can pick up the signals increases markedly as the plane gains altitude. Thus, at an altitude of 1,000 feet the range of these signals is 45 miles; at 5,000 feet the range has increased to 200 miles. These frequencies have the additional advantage of being static-free.

Another radar device, the radar altimeter, gives the pilot his altitude at any time, as the echo returned to him from the surface of the earth is registered on a scale indicating distance from the ground.

LORAN

Still another application of the radar principle is Loran ("long-range navigation"). During World War II all loran stations were operated by the U. S. Coast Guard, which has continued in charge of them since then. Loran makes it possible for a ship (or a plane flying over the ocean) to check its position within a radius of 900 miles in the daytime. At night, when reception is much better, the radius may go up to as much as 1,500 miles.

The principle underlying loran is that a network of stations on shore sends out signals that are perfectly synchronized. To obtain a loran reading, a navigator has to detect signals from two pairs of

Ship navigation has become much safer through the application of radar techniques. Loran makes it possible for a ship to check its location. PPI indicates the position of rocks, icebergs, other vessels, shoreline, etc.

stations. One station of each pair sends out short bursts of uniform length. After a brief but regular interval the other station of the pair repeats the bursts.

The ship's loran receiver and loran scope record the time lag between the two sets of signals. The navigator has special charts which plot a curve of a certain shape (a parabola) to fit every time differential.

Then the navigator receives signals in the same way from another pair of stations, yielding another parabola. When he plots the two parabolas on a map, they will intersect at some point; this is the location of the ship. Loran operates with a high degree of accuracy.

Although loran uses pulses of energy in the usual manner of a radar transmitter, no echoes are received. Loran operates on longer waves and lower frequencies than radar proper. Such waves bounce off the ionosphere and follow the curve of the earth. They are excellent

for ship navigation, as the surface of the ocean does not present any obstacles to transmission of the beams.

OTHER USES OF RADAR

Nowadays most commercial planes are equipped with airborne weather units that operate on the radar principle. In this case the radar scope reveals to the pilot the prevailing weather in the area toward which he is heading.

The principle on which this unit operates is that areas with turbulent rain and wind will produce strong echoes on the radar unit, whereas areas with good weather will not return any echo. This enables the pilot to deviate from his course as much as he needs to in order to avoid the bad weather. His radar unit tells him when it is safe to return to his course. The remarkable paradox of radar is that while it gives accurate information about the weather, its working efficiency is in no way affected by bad weather.

The use of radar as a navigational aid by no means exhausts its possible applications. For example, the United States Army Signal Corps used radar on January 10, 1946 at its laboratory at Belmar, N. J. to send a signal to the moon. Travelling with the speed of light, the signal made the round trip of some 476,000 miles in approximately 2.5 seconds. The signal was received audibly on a loud-speaker and visually by means of a cathode-ray tube. This gave an enormous impetus to the development of radio astronomy, described earlier in this chapter.

Radar has added a new dimension to weather forecasting. During the war it was noticed that microwaves caused vibrations in drops of moisture in the atmosphere. This phenomenon is known as "resonance absorption."

Further research showed that radar could be used in this way to study the arrangement of atoms in molecules. Here was a new kind of spectroscope for the study of molecular structure.

Another discovery was that microwave "echoes" can be obtained from cloud vapor, drops of moisture, and even fine particles of dust. There are distinctive differences among the received signals, depending on the mass and size of the object doing the reflecting. It follows that reception differs according to whether it is drizzling or raining heavily; and moderate rain, thunderstorms, and snow all have their distinctive echoes as well.

These characteristics have made radar ideal for weather forecasting. It is more dependable because it can report on a wider range of phenomena than conventional methods can.

An aircraft appears on the radar scope as a small white spot. Once it has been detected by radar, its position is indicated on a large plotting board and its subsequent course can be followed.

Turning to a totally different field, it has been found that microwave radiation is very effective in killing bacteria and crop-destroying pests. An Italian scientist named Longo has reported that when microwave radiation was applied to growing plants in moderate dosages, crops increased 10 per cent. This was doubtless due to the extermination of plant parasites. Longo's research also confirmed that when sun-spot activity is at its height in the sun, the increased microwave radiation at that time stimulates the growth of crops.

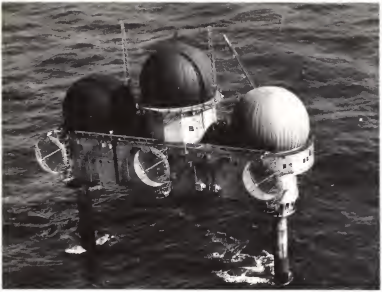
A combination of radar and sonar (page 122) in a machine called an "echograph" can diagnose the presence of cancer cells in 30 seconds by drawing echoes from tissues and projecting them on a fluorescent screen. (There is no damage to the living tissues.)

According to Dr. John J. Wild, the inventor of the echograph, "Cancer shows up because it reflects more echoes and more sound than normal tissue surrounding cancer. Non-malignant tumors show up because they reflect less sound than normal tissue." Dr. Wild believes that the echograph can also be used for examining the heart and blood vessels.

Even cooking can benefit by the application of radar techniques. Radar ovens are used very satisfactorily for heating precooked frozen foods in less than a minute. Very-short waves emanating from the radar tube are reflected against the metal sides of the oven toward the food. This causes the molecules in the food to move so rapidly that the cooking is completed in a matter of seconds. More elaborate dishes take about five minutes.

With such a rapid process no natural juices or flavors are lost, and the cooking itself is smokeless and odorless. This oven will be available for the average home when mass production reduces the unit price.

This radar oven remains cool while food is cooked in it by microwaves. No external heat from a flame or electric element is required.



An offshore radar station of the U.S. Air Force. The domes house radar antennas; below are operations and plotting rooms. Such stations provide the first warning of aircraft approaching from the sea.

BAT RADAR

When we marvel at the versatile and ingenious uses to which man has put radar, it comes as something of a shock to learn that bats apply the radar principle much more efficiently.

Bats emit shrill squeaks which vibrate 50,000 times a second. This is far beyond the range of human hearing, which has an upper limit of between 15,000 and 20,000 cycles per second; but bats readily hear in these high frequencies. According to Donald R. Griffin, professor of zoology at Harvard, "The high-frequency guidance system of bats is, ounce for ounce, a billion times more efficient than radars and sonars contrived by man."

When bats had their eyes taped up in the course of a scientific experiment, this did not stop them from flying accurately. But when their ears or mouths were taped up, the bats were at a loss. They were dependent on the amount of resonance in the echo of their squeaks to warn them when obstacles were present.

In another remarkable experiment, bats were placed in a totally

dark room strewn with a maze of fine wires. Radio loud-speakers blasted away at the same frequencies used in the bats' detection system. Undeterred by this "jamming," the bats had no trouble avoiding the wires placed in their flight paths. This feat is equivalent to human beings being able to converse in whispers right next to several multi-jet planes!

HOW TELEVISION WORKS

In a sense, the television camera tube operates in the same way as the human eye. As we saw earlier (page 44), the retina is made up of thousands of light-sensitive cells. When we look at a picture, we are really seeing a pattern of many thousands of "points" or "dots." But we ignore the dots and take in only the over-all pattern.

What creates a recognizable reproduction in any image is the contrast of light and dark. All this means is that certain sections of dots are lighter or darker than others. Electronic methods are applied in television to reproduce this pattern of light and dark.

The camera tube contains a large screen on which the scene to be

Closed-circuit television makes it possible to control traffic in different locations from a central source.

transmitted is focussed. This screen is made of mica and covered with millions of tiny silver spots coated with cesium salts. When light falls on the screen from the images coming from the camera lens, the silver globules receiving the light give off electrons. Where the light is stronger, more electrons are emitted.

The camera tube, which is a form of the cathode-ray tube, sprays electrons on the screen to replace the electrons that have been lost. Thus a constant supply of electrons is stored up in the globules for future use. The electron beam continuously scans the screen horizontally line by line, covering its 525 lines in 1/30th of a second. (This scanning process reminds us of the same process on the radar scope.)

The first practical camera tube was the iconoscope, invented by Vladimir Zworykin; nowadays it is used mostly for televising film. The image orthicon, a newer type of camera tube, is much more sensitive to light, enabling television performers in a "live" performance to work under lights only 1/10th as powerful as those needed for the iconoscope.

The job of the camera tube is to convert the picture into a stream of electrons. This creates electromagnetic waves that can be picked up by the aerial of a television receiver.

The function of the receiving equipment is to convert the electromagnetic signals into a visual image and audible sound. The flow of electrons is transformed into a pattern of dots determined by the pattern of the original televised picture.

The picture tube in the receiver produces an electron beam which is synchronized with the electron beam in the television camera tube. Variations in the flow of electrons will therefore create the right pattern of light and dark to reproduce the original picture. The inside of the picture tube has a phosphorescent coating which glows long enough for all the tiny points of light to combine into a recognizable pattern.

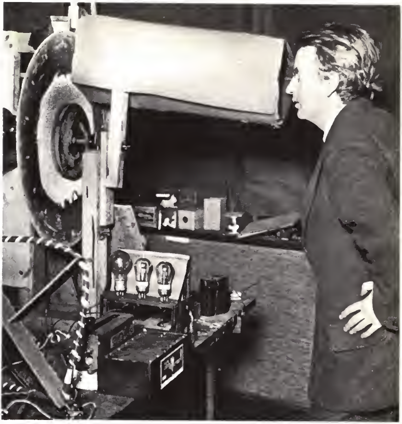
WORLD-WIDE TELEVISION?

Some day, perhaps by 1970, we will have world-wide television.

This would be easy enough to arrange if television used low-frequency signals, which are reflected back to the earth by the ionosphere.

However, television signals, which have to transmit sound and image, must use high frequencies which are 100 to 1,000 times higher than the low frequencies. The frequencies reserved for television are therefore in the VHF (very-high frequency) and UHF (ultra-high frequency) ranges. Here the figures are so great that they are measured in megacycles (millions of cycles).

The higher the frequencies, the more they tend to travel in a



This is John L. Baird, pioneer of television, who prepared a working television model in 1926 and demonstrated transatlantic and color television in 1928.

straight line, going through the ionosphere and out into space. At least this had been the orthodox theory.

After a series of tests that were declassified by the United States government in 1955, it was found that the VHF and UHF frequencies can be transmitted up to 300 miles — much greater distances than had been thought possible.

Various theories have been advanced to explain this surprising ob-

servation. Scientists believe some reflecting force is at work to drive the short waves back to earth. The reflection may come from the troposphere, or from the 10 billion or so meteors that pass through the ionosphere every 24 hours.

By using relay stations several hundred miles apart all over the world, it would be possible to set up a complete television network, but it would be a very costly affair, necessitating 50,000-watt transmitters and paraboloid antennas.

COLOR TELEVISION

Color telecasting has enormous technical complexities. In actual practice color television works fairly well with three basic colors — red, green and blue. The light-sensitive camera screen requires three kinds of phosphorescent coatings, each sensitive to only one of the three basic colors. For each color, an electron beam picks up the pattern.

In the television receiver, three electron beams — one for each primary color — are made to blend in the picture tube, thus recreating the original image in the proper distribution of color. This again requires three phosphorescent coatings, each one sensitive to a different basic color.

As can be seen, the process is quite complicated, and so far quite expensive. Undoubtedly color television will undergo a great deal of improvement and simplification in the years to come.

TELEVISION USES IN MEDICINE

We have already seen some uses to which television can be put in medical research and diagnosis. Here are other medical applications:

Cancer can be detected in its early stages by microscopic examination of smears for cancer cells. (These have larger nuclei than normal cells and they absorb more light.) But it is impractical to pursue this type of examination on conventional lines, as it takes too much work and time.

The Cytoanalyzer simplifies matters considerably. This device examines the cells with the aid of a microscope and then demonstrates the size and density of the cells on a television screen. The scanning of the cells by a Cytoanalyzer brings out light and dark contrasts, creating an image that gives the pathologist the data he needs.

Another routine but valuable job that has been greatly simplified by television technique is taking a blood count. The conventional way of doing this is slow and tedious; and in any mass emergency it would be pitifully inadequate.

By means of closed-circuit television these people can carry on a conversation face to face, although they are hundreds of miles apart.

The Sanguinometer is a television microscope that works with a computer to provide an instantaneous count of blood cells.

Television is also used in brain examinations in cases of epilepsy, brain tumors and other brain disorders. When the patient is subjected to external stimuli, the resulting electrical potentials in different parts of the skull appear as varying patterns of brightness on a television screen. The patterns are photographed with a high-speed movie camera and then projected at a lower speed, enabling the doctor viewing the film to observe the movement of the brain waves as the nervous system reacts to stimuli.

Color televising of an operation gives students a detailed picture of exactly what happens during the operation, with a better view of the whole procedure than they could obtain in any other way.

CLOSED-CIRCUIT TELEVISION

Closed-circuit television has many applications — in directing traffic, for example, and in controlling the movement of freight trains in railroad yards.

One interesting industrial use is in steel mills where hot slabs of steel are reheated at a temperature of 2,000 degrees. It is essential to position the slab precisely so that every part is heated uniformly. Since it is impossible to approach the furnace because of the intense heat, closed-circuit television is used to enable the operator to see at a distance what is happening in the furnace, and to maneuver the hot slabs by remote control with utmost efficiency and safety.

The field in which closed-circuit television is destined to have a valuable application is that of education. Progress thus far has been very slight, for a number of reasons. Initial installation is expensive, and funds are not readily allotted for what has been called a "gadget." Again, use of closed-circuit television would require retraining of teachers to learn new skills and techniques, and this takes time, willingness, patience and an experimental frame of mind. Eventually, however, educational television may overshadow all other uses of television.

SOUNDLESS SOUND

Sound waves which vibrate so rapidly that they produce sounds that cannot be heard by human ears are called "ultrasonic." Scientists have put ultrasonic waves to a remarkable variety of ingenious uses. One of the most valuable applications turned up in World War II as a supplement to radar.

Though radar can do many miraculous things, it cannot detect underwater echoes. But sonar, which also uses a cathode-ray tube,

A portable ultrasonic depth sounder which is powered by a storage battery. It gives accurate readings for depths of from 2 to 120 feet.

detects objects below the surface. Ultrasonic waves are directed down through the water, and when they strike an object the echo is reflected back to the sonar receiver. The strength of the signal indicates the nature of the object; the time it takes for the echo to return gives its distance; and a directional antenna gives the remaining information that is needed. Sonar proved a formidable weapon against submarines during the war.

Since then, it has been a valuable tool for determining the depth of the ocean in various places. With the use of echo-sounding equipment, scientists have discovered such underwater wonders as a mountain range under the Atlantic, and Pacific canyons that reach a depth of over 34,000 feet.

Sonar is also employed by fishing fleets to find the best fishing grounds. Vessels that were shipwrecked years ago are at last yielding their valuable secrets, thanks to sonar.

Ultrasonic waves have many industrial uses for inspection purposes. For instance, a reflectoscope shoots brief bursts of ultrasonic

This ultrasonic grinder is a remarkably accurate and delicate tool (see photo on facing page).

sound into metal bars, and any flaws that may be present are reflected back through a cathode-ray tube which projects the defects on a fluorescent screen.

Ultrasonic vibrations are also used to good effect in blending mixtures of metals. Where one metal is heavier than the other, it is ordinarily difficult to get a perfect mixture; but ultrasonic waves do the job admirably.

In the manufacture of chocolate the use of ultrasonic waves shortens the mixing process to 1/150th of the time needed when conventional methods are used.

Ultrasonic vibrations are powerful enough to kill bacteria with their shock waves. They form bubbles inside the germ cell; as the pressure

increases, the bubbles expand until they finally burst, killing the germ. This property of ultrasonic waves can be used to sterilize milk without affecting its flavor. At the same time the ultrasonic waves break the fat up into fine particles, so that the milk is homogenized — the cream is evenly distributed.

American and Soviet scientists have treated plants with ultrasonic waves and found that the plants flower sooner; crops are increased by as much as 50 per cent in some cases.

Ingeniously designed ultrasonic burglar alarms set off an alarm far from the scene of the burglary, without the burglar being aware that his crime has been discovered.

HOW ULTRASONIC WAVES ARE GENERATED

When a quartz crystal is cut in a certain way it is capable of generating electric voltage when pressure is applied. If alternating current is applied to such a crystal, it expands and contracts as the voltage alternates. This alternating rhythm is the method generally used to create ultrasonic waves.

Small metal plates fastened to the crystal move up and down as it expands and contracts. As the distances travelled by the plates are measured in ten-thousandths of an inch, hundreds of thousandths of changes in direction take place in a second. So the speed is really tremendous, and considerable energies are released to create ultrasonic sound waves.

THE FUTURE OF ULTRASONICS

Scientific research in this field is so varied that we may expect to see ultrasonic methods applied to all sorts of tasks which are unrelated to each other.

This beautiful engraving on glass was made with an ultrasonic grinder.

Ultrasonic therapy is being used to relieve pain in patients suffering from arthritis, neuritis, bursitis and similar ailments.

For example, powerful ultrasonic beams, focussed by electrical generators, may replace the conventional tools of surgery. Lengthy, delicate operations, like those on the brain, may be completed in a few seconds by these concentrated beams which can be localized to any desired degree.

We can get some idea of how such an ultrasonic "knife" would work from the use of an ultrasonic cutter to slice paper-thin slabs from a block of quartz. The slicing, accomplished without the cutter actually touching the quartz, produces "wafers" which are 12/1,000ths of an inch thick. The thinness of the slices has greatly increased the supply of quartz crystals available for many types of radio communication.

Washing machines and refrigerators may eventually operate with ultrasonic equipment. In the case of washing machines, it has been demonstrated experimentally that ultrasonic methods do a superior job in removing dirt; and they have the additional virtue, as we have seen, of killing germs. Ultrasonic waves can also be used to exterminate insect pests.

In industry, ultrasonic methods have valuable possibilities in purifying smoke, and in recovering carbon from industrial smoke, as well as acids from acid vapors.

Experimentation has shown that ultrasonic waves can be used to disperse fog. But since they also affect living creatures harmfully, this method needs practical improvement.

In the field of ultrasonics — and it is safe to say the same about radio, radar and television — we are sure to see amazing developments that will surpass the remarkable achievements that scientific research already has to its credit.

6. Radiation and the Atom

Long before the dawn of the scientific age, ancient thinkers speculated on the nature of matter. One of them, a Greek philosopher named Democritus, thought that matter was made up of tiny, invisible particles. It was a good guess — but only a guess.

Centuries later, John Dalton, an English schoolmaster, announced the Atomic Hypothesis which has been named after him. Matter, said Dalton, was made up of a number of basic substances — "elements." Each element was made up of "atoms" of the same size, shape and weight. All the atoms of the same element were alike, and they were all different from the atoms of any other element. (From our modern knowledge of "isotopes" — page 131 — we know Dalton was wrong on some points.) Atoms were indivisible, Dalton added; they were the smallest particles to which matter could be reduced.

At first Dalton's theory, which was published in 1803, met with ridicule and hostility. But as time went on, more and more scientists accepted his Atomic Hypothesis.

By 1869 scientists had discovered many additional elements. In that year Dmitri Mendeleyev published his Periodic Table of the then known elements, arranging them by order of increasing atomic weight.

Mendeleyev showed that elements arranged in systematic groups ("periods") on the basis of their atomic weights had similar characteristics. What is fascinating about Mendeleyev's work is that he found gaps in his table which, he said, represented elements that remained to be discovered! From the position of the gaps, Mendeleyev was able to predict the properties of the then unknown elements. His predictions were subsequently verified.

ATOMIC PARTICLES ARE DISCOVERED

Up to the end of the nineteenth century, scientists were virtually unanimous in believing that the atom was indivisible. In 1897 J. J. Thomson brilliantly shattered this theory with his discovery of the electron.

Courtesy, Union Carbide Corporation

A SWIMMING-POOL REACTOR: This self-photo was taken by the light of radiation within the core of a pool-type reactor at Oak Ridge National Laboratory. It gets its name from the fact that it is submerged to serve three functions: the water acts as a coolant, as a radiation shield, and as a moderator to slow down neutrons to intensify the chain reaction.

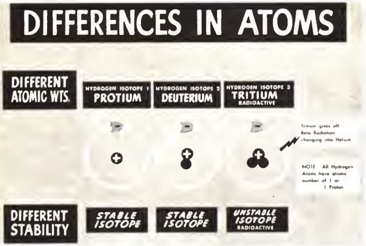
He did this by working with a Crookes tube, a near-vacuum through which an electric current was passed after a wire had been sealed into the tube. (This tube was the crude ancestor of the cathode-ray tube.)

As electricity passed from the cathode (the negative electrode) to the positive electrode, the latter began to glow with a bluish light. Using magnets to deflect the course of the rays, Thomson made some calculations. As he knew the amount of current, the strength of the magnets, and the degree of deflection, he arrived at the weight of the particles in the beam of light.

Thomson's calculations showed that the mysterious particles were lighter than the hydrogen atom — the lightest of all atoms. This meant that the atom contained a smaller particle; and, as the beam was attracted to the positive electrode, this particle was negatively charged. Thomson called this particle a "corpuscle," but "electron" soon became the universally-used term.

Since the atom as a whole is electrically neutral and the electron particle is negatively charged, scientists concluded that the rest of the atom must be positive. In 1911 Ernest Rutherford, another great scientist and Thomson's disciple, performed another notable experiment.

The cathode-ray tube is one of the most valuable of all scientific instruments. Its property of lighting up a fluorescent screen with an electron beam made radar, sonar and television possible. It has also proved useful in many kinds of scientific work.



Rutherford fired alpha particles (these are positively charged, as described on page 144) at sheets of gold with a thickness of 1/300,000th of an inch. Some of the alpha particles passed right through; others bounced off.

To the layman this would mean nothing; to Rutherford it was the basis for a far-reaching hypothesis.

Rutherford reasoned that most of the atom must be empty space; the alpha particles went right through the gold atoms at those points. But where the particles bounced off, it meant they had hit a solid core of positively charged particles inside the gold atoms. Like charges repel like charges, so naturally the propelled particles bounced off.

The atom, then, had a solid core — a "nucleus." The comparatively weightless electrons must be in the empty space, held to the nucleus by the mutual attraction of positive and negative particles. Later on, the positive particles in the nucleus were named "protons."

In 1932 Sir James Chadwick, an associate of Rutherford, discovered a third atomic particle, the neutron; as its name implies, it is electrically neutral. With this discovery, as we shall see, atomic physics was on the verge of controlled atomic fission.

STRUCTURE OF THE ATOM

Thanks to these epochal researches, our present-day knowledge of the atom has broadened considerably.

Of the 102 basic substances called "elements," 92 occur in nature

and 10 more are man-made. An atom is the smallest part of an element which still retains the properties of that element. Atoms are so tiny that 100 million placed end to end would be an inch long.

Practically all of the atom's mass (99.9 per cent) is concentrated in the central part, the nucleus. This is made up of positively charged protons and electrically neutral neutrons. Around this nucleus negatively charged electrons whirl in orbits to which they are held by the electrical attraction of the protons.

Actually, the atom is mostly empty space. If the nucleus were magnified to the size of a pea, the space between the nucleus and an electron would be about a mile.

The nucleus, moreover, has such a high density of protons crowded together that a mere thimbleful of protons would weigh several tons. A proton (a neutron, too) has a diameter of about a 45/quadrillionth of an inch. An electron is larger — it has a diameter of about a 25/trillionth of an inch, but it weighs only 1/1850th as much as a proton.

WHY ARE THE ELEMENTS DIFFERENT?

In each atom, under normal conditions, the number of electrons equals the number of protons. This keeps the atom in a state of electrical balance.

Each element has a characteristic number of protons and of electrons in its atoms. This is called its "atomic number." The chemical properties of an element are determined by the number of electrons its atoms contain. Change the number of protons and electrons in an atom, and you get a different element. This is the logic behind Rutherford's early "atom-smashing" experiments and the great particle accelerators; it is also what happens in the "decay" of radioactive elements (page 144).

Every different kind of atom is an atom of one element or another. There is no such thing as a "proton of oxygen" or an "electron of nitrogen." Protons and electrons are the "building blocks" of atoms.

ISOTOPES

"Isotope" is a Greek word meaning "same place." In chemistry, it refers to the place of an element in the Periodic Table.

An isotope of an element is an unusual form of an element; the isotope has the same number of protons and electrons as the common form, hence the same atomic number and the same chemical properties. But the *atomic weight* of the isotope differs from that of the common form of the element.

The atomic weight of an element is the total of just the protons and neutrons in its atomic nucleus. *Every isotope differs by at least one neutron from the common form of the element;* hence the difference in atomic weight.

The simplest examples of isotopes occur in the case of the hydrogen atom. In its common form, hydrogen has one proton, one electron, and no neutrons. This is the most basic form an atom can have, and the hydrogen atom is the lightest of all atoms. Its atomic number is 1, its atomic weight is 1.

But in the great decade of nuclear studies — the 1930's — it was found that one out of every 5,000 hydrogen atoms contains a neutron. This gives us a hydrogen isotope — "deuterium" — with one proton, one electron, and one neutron; its atomic number is still 1, but its atomic weight is 2.

Tritium is an even rarer hydrogen isotope, containing one proton, one electron and two neutrons; its atomic number is still 1, but its atomic weight is 3.

Lest this all seem too remotely theoretical, it should be mentioned that one of the most exciting stories of World War II centered about British attempts to destroy a German plant for processing "heavy water," water which contains deuterium instead of ordinary hydrogen. As a moderating element in uranium fission, heavy water was needed by the Germans for their atom-bomb research. Tritium is even more vitally important, as it is the indispensible component of the infinitely more destructive hydrogen bomb. The most powerful bomb uses a combination of deuterium and tritium. 1647

THE NATURE OF ATOMIC RADIATION

It is curious that some of the basic discoveries in the realm of atomic physics (X-rays, radioactivity, and the electron) were made within a period of two years by scientists working independently of each other.

The link that connects all these phenomena was later explained by another great physicist, Niels Bohr. For, from his studies of nuclear structure, it appears that electrons are knocked out of their orbits (shells) by collision with other particles. In the process they lose energy, which is given off in the form of photons (or quanta) of light — as described on page 31.

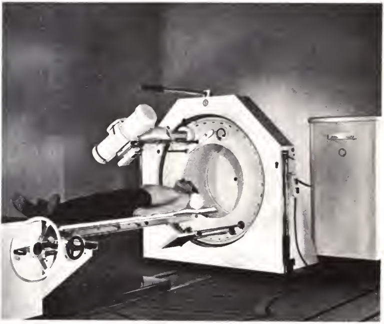
Each orbit has a definite amount of energy, so that the kind of photon (or quantum) that is emitted will depend on which orbit it came from. The conclusion has been that no matter what form radiation takes, it is all produced by electrons changing their orbits.

THE MYSTERIOUS RAYS

Late in 1895 Wilhelm Conrad Roentgen of the University of Wurzburg was experimenting with a Crookes tube through which he passed an electric current after filling it with a gas. The tube was covered with black paper and the room was darkened. To his astonishment, some photographic plates coated with barium salts, which happened to be in the room, began to glow.

When Roentgen turned off the current, the glow disappeared. He guessed that the action of the cathode rays on the gas was causing the emission of a mysterious, hitherto unknown, form of radiation.

Fascinated by his discovery, Roentgen decided not to make it public until he had tested the new rays thoroughly; though from the start they were destined to be called "X-rays" — "x" for the unknown. When he held a fluorescent screen in front of the black-covered tube, the screen lit up as soon as he turned on the current. When he interposed



In X-ray treatment of cancer cases, the X-ray beam is focussed directly on the diseased cells. Sometimes the cancer cells are destroyed; in other cases, where the diseased cells are hardy, their aging process is speeded up by the radiation, so that they are slowly destroyed.

X-ray techniques are useful in many forms of scientific research. This X-ray picture enabled scientists to study the brain structure of a corpse buried in a swamp for centuries.

a thick book between the tube and the screen, the result was the same: the screen lit up. Now Roentgen knew that the mysterious rays were extremely penetrating.

In further tests with the X-rays, Roentgen found that when the rays were trained on his hand, they passed through the flesh but stopped at the bone. His bones were clearly outlined in the mysterious glow on the screen.

Within a few months after Roentgen's announcement of his discovery at the end of 1895, hospitals were using X-rays for a variety of medical purposes — diagnosing tuberculosis, cancer and other diseases, including tooth decay, getting exact information about the state of internal organs. Today millions of X-ray pictures are taken in a year in the United States alone.

Two strange things were noticed about X-rays fairly early. Incautious exposure to large doses of X-radiation could be very dangerous; and yet, precisely this penetrating quality of X-rays made them valuable in the attempt to kill the diseased cells of a cancer victim.

Roentgen's investigations showed that in some respects X-rays behaved like electricity and light, but it was not until 1912 that their electromagnetic character was fully demonstrated (page 140).

HOW X-RAY EQUIPMENT WORKS

Basically, man-made X-rays are formed in a tube by directing an electron beam at a target metal which has a high melting point. Tungsten, which melts at 4,000 degrees Centigrade, is a favorite metal for this purpose. When the electrons strike the metal, X-rays are emitted.

But there is an immense gulf between the old, crude equipment of 50 years ago and the tubes used today to supply X-rays for cancer treatment. Some of these tubes are 10 feet high, and they create rays more powerful than could be supplied by all the radium in the world — $18,000,000 worth. To operate such a machine for an hour costs less than a dollar.

When the electrons left the cathode (negative electrode) and struck the anode (positive electrode), 99.8 per cent of their energy was released as heat, causing the tube to glow. The remaining 0.2 per cent was released in the form of (invisible) X-rays.

What actually happened in the impact of the electrons on the positive plate? One possibility — a rare one — was that an electron was absorbed by an atom of the positive plate. In this case an X-ray was released.

A much more frequent occurrence was this: the electron merely bounces off an atom, giving off most of its energy in the form of an

X-ray. The electron might then continue to collide with other atoms, each time with progressively diminished energy, as a result giving off progressively weaker X-rays.

The problem, then, was to convert the electron beam from the cathode into less heat and more powerful X-rays. One of the most valuable improvements was the introduction of a rotating anode, driven at a speed of 3,000 revolutions per minute. The object of this was to expose as little of the anode as possible to bombardment from the cathode rays (the electron beam). Consequently most of the heat was conducted away from the cathode rays, with the result that more powerful X-rays were formed.

Later research revealed that the smaller the anode, the sharper the images on X-ray plates. So there was an additional advantage in using the rotating anode.

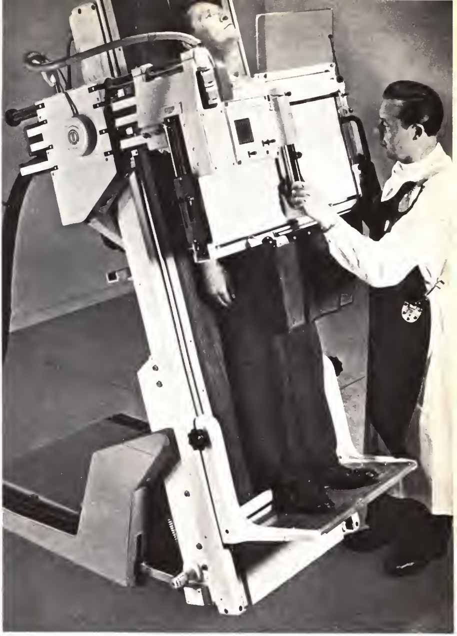
To make sure of getting the high voltages needed in the modern X-ray tube, X-ray generators were introduced. These generators contain a transformer to raise the voltage to a point high enough to produce powerful X-rays. They also contain a rectifier to change our customary alternating current to one that is practically direct current. This is essential, as the movement of the electron beam from cathode to anode is a one-way trip.

Another difficulty encountered in the perfecting of X-ray technique was that X-rays directed at the patient's body would become diffused by secondary radiation emanating from atoms in the body.

This difficulty was cleverly solved by placing lead strips in a framework so that they would block any radiation entering at an angle and allow the entrance only of radiation that was perpendicular to the target or nearly so. (Lead makes a good shielding against even the most penetrating radiation.) In order to eliminate any shadow from the lead strips, they are made to move slowly and thus do not appear on the film; for any object that moves will "erase" itself from an X-ray image.

One of the earliest — if not the earliest — cases on record of X-ray treatment occurred in 1903 when Dr. Nicholas Senn of Chicago treated a leukemia case with X-radiation. From then on, doctors began to treat various types of cancers with X-rays on a trial-and-error basis. Lacking a thorough theoretical knowledge of the subject, they advanced slowly by means of painstaking experiments. Not a few radiologists became martyrs to science by absorbing excessive amounts of radiation.

One of the most important steps was the measurement of radiation in terms of a definite unit — "the roentgen." Intricate calculations are needed, and in our own time scientists are still striving for greater



X-ray chest examinations enable doctors to diagnose tuberculosis and lung cancer in the early stages.

The X-ray diffraction scope is used for the study of chemical reactions, identification of chemical substances and alloys, and testing materials for their ability to withstand hard wear. This instrument is so sensitive that it can measure distances as tiny as 1/250,000,000th of an inch.

precision in measuring radiation. This is of the greatest importance in establishing uniform treatments and dosages for X-ray therapy. Calibration of X-ray units in order to produce a definite dose of radiation is still an art and requires highly specialized skill.

With Coolidge's perfecting of the tungsten filament (page 38), X-ray tubes were greatly improved and became much more reliable. Voltages of 200,000 volts became feasible for cancer cases.

Another remarkable improvement resulted from the use of selected metals to filter the radiation and eliminate the less penetrating rays which only damaged the skin without entering the body. In time, voltages were raised to 1 million volts and then to 3 million volts. Today the particle accelerators such as the synchrotron are used to give tremendous acceleration, resulting in 22 million volts and even more.

X-ray therapy was further improved by research on the effects of radiation. These studies showed that the best method was to use some-

what smaller doses of radiation in a series of treatments. This had less harmful effects on healthy tissues and yet was just as effective in destroying cancerous tissue. (Examination under the microscope shows that the cancerous tissues just "melt" away.)

Certain types of tumor cells are comparatively resistant to the X-ray beam. But, while these cells are not immediately destroyed, the radiation does have the effect of speeding up their aging process, so that they gradually die. The desired effect is attained, but it takes more time.

OTHER MEDICAL USES OF X-RAY

X-ray therapy has also proved extremely effective in treating a variety of inflammations of tendons, muscles and joints. These crippling and painful ailments were previously incurable. Many types of disfiguring skin diseases are also treated successfully by X-ray therapy.

The use of X-rays in dental work has brought about an enormous advance in all aspects of dental treatment.

Surgery has benefited by the introduction of X-ray stereography, for in some cases of diagnosis prior to operating, it is valuable to get a third dimension in the area. This is done by taking first one X-ray film and then another X-ray a short distance away — approximating the distance between the eyes. If the surgeon now sees the two films through a special stereo viewer, it is as if he is seeing the image with the naked eye; a valuable impression of depth is created which is very revealing to him.

NEW X-RAY DEVICES

The combination of X-rays and microscope is a very attractive one, as it enables scientists to observe what goes on in a seemingly opaque cell. A new type of microfluoroscope has been invented by Dr. Howard H. Pattee, Jr., director of Stanford University's X-ray research laboratory. This microscope, which shows rather long X-ray waves, can analyze specimens down to 1/25,000th of an inch in diameter, or 3/trillionths of an ounce in weight.

The microscope utilizes a focussed beam of electrons fired at an aluminum target. This in turn produces a focussed beam of X-rays which pass through the object and are then projected on a green fluorescent screen. This screen, according to Dr. Pattee, "is just about a million times finer than the screen on a television tube." The new instrument, which can be used on living things, is proving its value in a long-range study of cell components.

Even more remarkable is the "Lumicon," the invention of Pro-

fessor Russell H. Morgan of Johns Hopkins University and Ralph E. Sturm, a research physicist. The Lumicon is an intensifier — it can increase, up to 50,000 times, the original light coming from an outside source. The intensifier is a valuable intermediary between a camera and a picture tube in a closed-circuit television arrangement.

The Lumicon was inspired by familiarity with some of the drawbacks of the X-ray fluoroscope. The latter produces only a dim shadowgraph picture of the patient's anatomy; the X-rays pass through the patient's body and create an image on a fluorescent screen. In the past, getting a brighter image would have meant using more penetrating rays, and these would have been harmful to the patient, and the doctor as well.

With the Lumicon, however, it is possible to use *weaker radiation* and get *brighter pictures;* and in addition, the television camera enables the doctor to view the image in another room, protected from any possibility of harmful radiation.

The Lumicon has also made it possible to get the most precisely focussed X-ray beams directed at cancer cells in treating patients; the exceptional clarity of the image heightens the effectiveness of treatment.

The powerful intensifying force of the Lumicon will also have many applications in astronomy, industrial inspection and other fields.

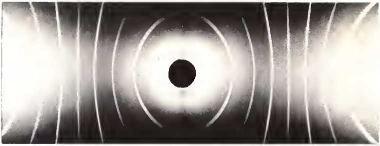
X-RAYS FOR SCIENTIFIC RESEARCH

Some of the most important scientific discoveries of our time have been made with the aid of X-rays. An impressive example of this was inspired by the verification, in 1912, of the electromagnetic character of X-rays. The great Rutherford, with his flair for bold, far-reaching investigations, acted on this discovery by asking Henry Moseley, his most gifted pupil, to prepare X-ray analyses of all the known elements.

By bombarding target elements with electron beams from a cathode-ray tube, Moseley discovered that the X-radiation given off provides a characteristic set of X-ray spectrum lines for each element. Thus a new method of detecting the presence of any element was devised.

Moseley showed that the wave-length of any X-ray line on the spectrum is inversely proportional to the square of the element's atomic number. He verified by X-ray analysis that the positive charge on the nucleus is identical with the element's atomic number (the number of protons in the nucleus).

Moseley also corrected errors in Mendeleyev's Periodic Table and constructed a better one on the basis of atomic numbers; Moseley's groups of related elements were based on the number of electrons in each kind of atom.



The internal structure of tungsten as revealed by the X-ray diffraction scope after a 30-minute exposure.

Moseley's analysis has been proclaimed a work of genius, but he did not live to enjoy fame, as he was killed at Gallipoli a few years later, in World War I, at the age of 28.

Nevertheless, his X-ray methods have continued to be used, as they will identify an element which is present in a substance to the extent of one part in 100,000. The subsequent application of Moseley's X-ray methods has resulted in the discovery of several elements which were unknown in his day.

X-ray techniques have also spurred epoch-making advances in the field of genetics. In 1926 Professor Hermann J. Muller, one of the world's foremost geneticists, showed in his famous experiments with fruit-flies that it was possible to create innumerable mutations in living creatures by subjecting them to X-radiation and thus apparently damaging the chromosomes — the carriers of heredity.

(In these days of alarm over fallout from atomic and hydrogen bombs, it requires an effort for us to realize that at the time of Muller's experiments, the only sources of potentially harmful man-made radiation were X-rays and radium.)

Later on, geneticists became aware of the importance of DNA (deoxyribonucleic acid), a substance that is thought to determine heredity and to control the activity of all living cells from their nuclei. As DNA is the basic component of the life process, it may well be that the first living creatures on earth were simple, crude specimens of DNA.

Aside from controlling heredity, DNA is known to be the main

component of many kinds of disease-causing viruses. If most types of cancers are caused by such viruses, as some geneticists believe, then scientists may learn how to fight cancer by synthesizing DNA, a discovery announced late in 1958.

In 1953 two British scientists, James D. Watson and Francis H. Crick, discovered by means of X-ray diffraction studies that DNA has a double-helical structure (in the shape of two interlinked spiral stairways). This was a big step toward the synthesis of DNA.

X-RAY USES IN INDUSTRY AND EVERYDAY LIFE

X-ray scrutiny of industrial equipment plays an important part in showing up hidden flaws in a variety of products. This is particularly true of parts that receive a great deal of stress, such as propellers for planes or vessels.

X-ray examination of automobile and plane parts has become routine. Breaks in insulated wires and cables can be found by the same method. Corrosion in metal sheets is discovered in good time through the use of X-ray films. Defects in rubber tires, glass equipment and plastics products are likewise unearthed in this way. Literally hundreds of other products are improved by X-ray inspection.

X-ray study of the welding work on Hoover (Boulder) Dam in Nevada was of immense importance in making certain that the huge structure would successfully withstand the terrific pressures to which it is exposed.

In making phenomenally accurate measurements of very slight thicknesses, as in the case of metal foils, glass lenses and paper, the X-ray beam has proved of incomparable value.

Again, in preparing alloys and other kinds of mixtures, the X-ray machine enables the processor to get accurate mixing of the components, especially where they have radically different qualities. Each substance has its own special wave-length, so that the X-ray analysis is absolutely reliable.

When X-rays are passed through crystals, the rays are diffracted. This reveals the internal patterns in which the crystals are arranged. The X-ray beams show us that combinations of atoms and molecules are arranged in regular crystalline planes.

This knowledge has many practical applications. It is used, for example, in studying the tensile strength of rayon, in checking the resistance properties of steel girders, in testing the efficiency of watch springs, in improving the covering quality of pigments, as well as in distinguishing between normal and diseased body tissue.

These are only a few of the myriad uses that have developed from

the diffraction properties of X-rays. The distances measured may be as tiny as 1/250,000,000th of an inch.

The diffraction technique is also important in determining the stress qualities of the same substance prepared by different methods. Although the substance will look alike in each case, its internal composition may be radically different, and X-ray diffraction reveals it. This is particularly important in the manufacture of steel and other metals which are required to withstand terrific stress.

X-RAYS DETECT FORGERIES

Like ultraviolet and infrared radiation, X-rays can be used to detect various kinds of forgeries—stamps, documents, paintings.

The most sensational use of X-rays in this field was the revelation of the "masterpieces" of the famous Dutch art forger Van Meegeren, who had collected large sums from his fantastically clever forgeries of Vermeer and other celebrated artists.

X-ray examination will also detect counterfeit coins and false diamonds. This is due to the fact that the bogus substance will have a different wave-length from the genuine substance.

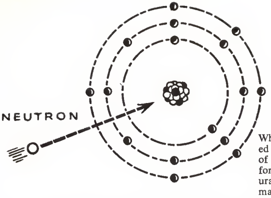
RADIOACTIVITY IS DISCOVERED

Henri Becquerel was a noted French physicist who specialized in studies of fluorescence and phosphorescence. When he heard of Roentgen's thrilling discovery of the mysterious X-rays, he wondered whether there was something to be learned from the fact that the coating of the fluorescent screen was mostly uranium salts.

In the course of his investigations he happened to leave some uranium sulphate with a piece of sensitized photographic paper in a drawer. Several days later he opened the drawer and found that a shadow had formed on the sensitized paper. Repeating the process with various kinds of uranium salts, he obtained the same result each time: a dark area formed on the sensitized paper.

In March 1896 Becquerel announced his discovery, stating his belief that the change in the paper was caused by an unknown kind of radiation. In some ways this new radiation resembled X-rays; in other ways it was different.

Now Becquerel turned to pitchblende, the chief uranium-bearing ore. To his astonishment, he found that the intensity of the radiation became much stronger instead of weaker. The pitchblende, he realized, must contain some substance that surpassed uranium in its power to emit radiation. He turned over to his most gifted pupil, Marie Curie, and her husband Pierre Curie, the job of discovering the substance.



When atoms are bombarded with neutrons, an isotope of the target element is formed. If the target is uranium, a chain reaction may be started.

It took the Curies years, working with the crudest kind of equipment, to track down the secret of pitchblende and the strange radiation. Their quest ended with the isolation first of radium chloride and eventually radium itself — which occurs in the ratio of one part radium to every 3 million parts of uranium. The Curies hit on the name "radium" because this substance radiated energy — gave off rays that were even more penetrating than X-rays — as well as a great deal of heat. They called this process "radioactivity."

Scientists marveled at this discovery. But Rutherford, barely in his thirties, subjected radioactivity to searching study and came to the conclusions that opened up dazzling vistas to the physicists of his day.

Radioactivity, Rutherford announced, was the breaking-up of unstable atoms. Experimenting with radium (more precisely, radium chloride), uranium and thorium, he found that they were all radioactive. By deflecting the radiation with powerful magnets, he discovered that it was divided into three kinds, which he called "alpha," "beta," and "gamma."

Alpha particles are positively charged, and are made up of the nuclei of helium atoms (2 protons, 2 neutrons).

Beta particles, or fast electrons, are negatively charged.

Gamma rays are electromagnetic waves (page 10), with very high frequencies and very short wave-lengths. They are extremely penetrating and very injurious to living tissue.

Most exciting of all was young Rutherford's conclusion: radioactivity is a process by which unstable atoms get rid of the particles that make them unstable. *As atomic particles are thrown off,*

Courtesy, Union Carbide Corporation

THIS CESIUM IS WORTH 2 MILLION PENNIES: Here is a dramatic photo of a cesium-137 source backed by a one-cent coin to show the relative size and the intensity of visible radiation emanating from the radioactive metal. Cesium is used increasingly in medical therapy equipment and in making radiographs to determine flaws in industrial castings. It has a half-life of 30 years.

the original element changes into another element. These changes ("transmutations") occur several times. It takes uranium several billion years to turn into radium, which after several transformations eventually turns into an isotope of lead, which is stable. Thus the radioactive process comes to an end.

Each kind of radioactive atom "decays" at its own characteristic rate. Scientists measure radioactivity by the time it takes an atom to emit half its radioactive energy. This is called its "half-life." Uranium has a half-life of billions of years. Polonium 214 (a radioactive isotope) has a half-life of 1/10,000th of a second.

Rutherford showed that in a single gram of radium 35 million atoms disintegrate in one second. Was it possible to imitate this natural radioactivity and release stupendous quantities of energy by artificial means? Eventually physicists found the answer to this question in atomic fission.

In the radioactive process, one element is transmuted into another by emission of energy from the atom. Could the scientists cause transmutation of elements by applying energy to the atom from external sources? What would happen if they bombarded the atom?

The second question was the first to be answered — by Rutherford, in 1919, with one of his simple, bold and far-reaching experiments. He placed nitrogen gas and a radium isotope in a tube and set up a fluorescent screen nearby. Alpha particles leaving the radium isotope at a speed of 9,000 miles a second bombarded the nitrogen nuclei.

What happened was what Rutherford had anticipated: the impact of the alpha particles with their two protons (page 144), added to the seven protons of the nitrogen, created a new nucleus of nine protons. The violence of the impact caused one proton to be ejected, and a stable nucleus of eight protons (an oxygen isotope) was formed.

From time to time, flashes of light appeared on the fluorescent screen. Could these be from the alpha particles? No, for the screen had been placed beyond the normal range of alpha particles. Hence the flashes must have come from the ejected protons, indicating that some oxygen atoms had replaced some nitrogen atoms.

This was the first man-made transmutation of elements. Other scientists tried their hand at such transmutations, but, while the prospects were enthralling, the results were disappointing. From 1919 through 1928 there seem to have been only 27 successful transmutations. Einstein later commented that these attempts were "like trying to shoot birds in the dark in a country where there are not many birds in the sky."

What was needed was some way of accelerating the speed of the bombarding particles so that they would be much more likely to disturb the normal state of the target nucleus. A speed of 9,000 miles per second seems tremendous to us, but compared to the speed of light (186,000 miles per second), it is trifling.

PARTICLE ACCELERATORS

Ernest O. Lawrence solved the problem by designing the first particle accelerator in 1931 at the University of California's Radiation Laboratory. This was the cyclotron, a device for forcing atomic particles to travel huge distances around a comparatively small circular path while they were speeded up by successive "kicks" of electron volts. (An electron activated by one volt is said to have an energy of one electron volt.)

In effect, the cyclotron is a large electrical motor which instead of the conventional rotating armature has a revolving stream of atomic particles. The natural tendency of the particles would be to move straight ahead, but powerful electromagnets deflect the particles so that they move in the circular path laid out for them.

The voltage is steadily increased, and each such increase accelerates the speed of the particles. When the desired acceleration has been reached, the beam of particles is forced to fly out at a predetermined point to strike a selected target. This serves many useful experimental purposes, which involve the collision of the tremendously accelerated particles with target particles.

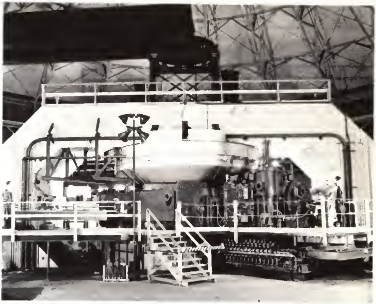
In the original cyclotron Lawrence used several kinds of particles for acceleration: protons, accelerated to 10 million electron volts; deutrons (heavy-hydrogen nuclei), accelerated to 20 million electron volts; and alpha particles (helium nuclei), accelerated to 40 million electron volts.

LINEAR ACCELERATORS

While popular attention has been focussed on the circular accelerators, there is also another type, known as a "linear accelerator." It was invented in the 1930's by Professor Robert Van de Graaf of Massachusetts Institute of Technology.

In a linear accelerator, atomic particles are forced in a straight line through a series of tubes which are alternately charged positively and negatively. The voltage is increased each time the particles enter another tube, so that their speed is correspondingly accelerated.

The same amount of time is allowed for passage through each tube.



The huge cyclotron at the University of California whirls around deuterons at energies of 200 million electron volts, alpha particles of 400 million electron volts, and protons of 350 million electron volts. This is the largest of the three cyclotrons built by Nobel prizewinner Ernest O. Lawrence, who invented the cyclotron.

But, as the speed increases progressively, it is necessary to make each tube longer. The dimensions have to be calculated with the utmost precision. Acceleration takes place only if each increase in voltage is perfectly synchronized with the departure of the particles from each tube.

Obviously the changes in voltages have to be made with fantastic rapidity. This became possible through the perfecting of oscillators as a by-product of radar research (page 107). The accelerator constructed by Luis W. Alvarez at the University of California in 1947 speeds up protons to 32 million electron volts. This calls for a chamber 40 feet long, using 27 radar oscillators capable of 200 million oscillations per second.

A later linear accelerator built at Stanford University is 100 feet long, attaining maximum energies of 1 billion electron volts.

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TYPES OF CYCLOTRONS

The design and construction call for many kinds of scientific skills. It has been said that these superb machines are to the twentieth century what cathedrals were to the Middle Ages. The designers have lavished a wealth of ingenuity on them, and each succeeding model is more daring and more costly. Scientists say jokingly that the cost of building accelerators runs into "megabucks" (millions of dollars).

The betatron, invented by Donald Kerst at the University of Illinois in 1940, is called the "doughnut" because of its shape. Beta particles (fast electrons) are gradually accelerated around a circular path to reach a final energy of 300 million electron volts, when they strike a tungsten target and give off gamma rays.

The first synchrotron, designed by E. M. McMillan of the University of California in 1946, used gamma rays to produce mesons (page 152), with accelerations up to 335 million volts.

Both McMillan and Vladimir Veksler of Russia independently solved the problem of dealing with increasing mass in accelerated particles. According to Einstein's Special Theory of Relativity, the mass of a moving object increases as its speed increases. This is an important consideration in designing particle accelerators: as the acceleration continues, the mass of the atomic particles increases. Adjustments must be made in order to synchronize the increases in mass and the increases in voltage. McMillan and Veksler both supplied the necessary mathematical equations for the adjustments.

The bevatron at the University of California is the largest particle accelerator in the United States. Using electromagnets that weigh 10,000 tons, it whirls protons around the circular path 4 million times in 1.85 seconds, covering 300,000 miles for an effective speed of 160,000 miles per second. The maximum energy attained is over 6 billion electron volts. (A billion electron volts is abbreviated "BEV," hence the name of the accelerator.)

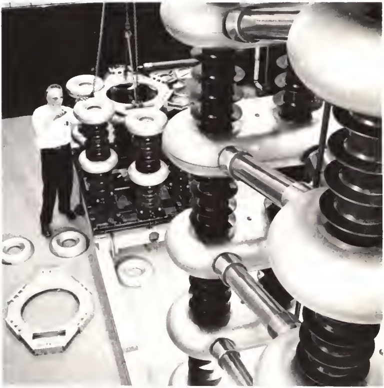
In 1955 Professor Veksler announced that the Soviet Union was completing a larger accelerator, capable of propelling atomic particles at maximum energies of 10 billion electron volts. It is called a "synchrophasotron" and requires electromagnets weighing 36,000 tons. It is said that before striking their atomic targets, the particles are hurled around 4,500,000 times in 3.3 seconds, covering a distance of 600,000 miles. This is an effective speed of 181,818 miles, very close to the speed of light.

At Brookhaven National Laboratory, Long Island, New York, an "Alternating Gradient Synchrotron" is under construction with a view

to employing energies of between 30 and 35 billion electron volts. (It will be the biggest particle accelerator in the world at the time of completion, but the Russians have now announced that they are building a 50-billion-electron-volt accelerator.)

The Brookhaven accelerator will use a variety of bombardment material — protons, neutrons, mesons, and also various forms of anti-matter. (The latter are particles which result in mutual destruction whenever they collide with particles of matter.) The emphasis, however, will be on protons.

The accelerator will use 240 magnets, each seven feet long. They



This Cockcroft-Walton machine gives protons their initial acceleration before they are forced into a linear accelerator, where the energies are stepped up until they are forced into the orbit of the bevatron.

will be arranged in a circle more than half a mile in circumference, and will be buried underground in a concrete frame 18 feet high. The magnets will be wound with 23 miles of copper bars one inch thick and two inches wide. It will be necessary to pump 2,000 gallons of water in and out every minute to cool the magnets.

The tunnel will contain a vacuum chamber 3½ inches high and 6 inches in diameter. The beams of particles will be forced through this chamber and gradually accelerated to energies of 30 to 35 billion electron volts. They will make the half-mile trip 350,000 times a second, for an effective speed of 175,000 miles per second.

The magnets deflecting the beam into its circular path will be so powerfully focussed that deviation will amount to less than an inch sideways or half an inch up and down in the course of travelling 175,000 miles.

As the particles circle around the course, the voltage will be stepped up 100,000 volts at a time by twelve radio-frequency accelerating stations. When the machine is in complete working order, it will produce a burst of 100 billion particles every three seconds.

The accelerator is so complex that it will take two hours to throw all the switches to operate it. Its initial cost is estimated at $25,000,000, plus another $225,000,000 for running it the first ten years.

The Midwest Universities Research Association plans a novel particle accelerator to force two accelerated beams of protons moving in the same orbit but in opposite directions to collide head-on. This daring technique was proposed by a Japanese physicist working for the association.

The energies applied would amount to 15 billion electron volts, but it is believed that because both beams will be in rapid motion, the force of the collision would use up practically all the energy of the moving particles. This has been calculated to amount to the fantastic total of 540 billion electron volts.

Each beam would contain 10 quadrillion protons and when the accelerator is operated at full power there would be a million collisions per second.

The chief purpose of this accelerator would be to discover now unknown subatomic particles and study them. If no new particles were discovered, it would be reasonable to assume that we now have a complete inventory of these particles.

The huge circular track would be 1,000 feet across and would require magnets weighing 62,500 tons. The initial cost is estimated at $100,000,000.

THE VALUE OF ACCELERATORS

What benefits has science derived from the particle accelerators? What has been achieved with them?

Since atomic particles cannot be seen under the microscope, the accelerators have given scientists an insight into the nature and behavior of these particles that could not be obtained in any other way. Systematic observation of these processes has trained a whole new generation of young physicists.

Before the days of the accelerators, no one dreamt that man could create new elements which do not exist in nature. But once Rutherford had transmuted nitrogen into oxygen, it seemed at least theoretically possible to create new elements by changing the contents of the atoms of known elements.

All the elements of atomic number 83 or higher in the Periodic Table are naturally radioactive. They have a disproportionately large number of protons and neutrons packed into their densely crowded nuclei. Their radioactivity is a natural consequence.

The heaviest element found in nature is uranium (atomic number 92, which means that it has 92 protons in its nucleus). In the old textbooks, the Periodic Table always ended with uranium. Today it shows ten additional man-made elements, as follows:

Atomic Number	*Name*
93	neptunium
94	plutonium
95	americium
96	curium
97	berkelium
98	californium
99	einsteinium
100	fermium
101	mendelevium
102	nobelium

These are all known as "transuranic" elements (those with atomic numbers higher than 92). All of them were created by the use of particle accelerators, starting with the laboratory transmutation of uranium into neptunium (23 minutes), followed by the transmutation of neptunium into plutonium, which takes about 56 hours.

The latest of the man-made elements (atomic number 102) has a half-life of three seconds. Physicists believe that another six or eight of

these man-made elements still remain to be discovered. Particle accelerators will furnish the means.

"STRANGE" PARTICLES

Scientists once considered the atom as the smallest particle of matter. Later they came to think of protons, electrons, and neutrons as the smallest particles of matter. But ever since 1937 they have been discovering even tinier particles of matter by the use of particle accelerators and adaptations of C. T. R. Wilson's cloud chamber.

Invented in 1896, the cloud chamber has been improved in many ways since then. It contains a substance which has been saturated with water vapor and then suddenly expanded. When charged particles are forced through the cloud chamber at high speed, droplets of water cling to the ions formed along the path of the particles. The tracks are photographed with high-speed equipment and can be studied at leisure later on.

When a magnetic field is applied to the chamber, the paths are deflected into curves that are characteristic of different kinds of particles and radiation. Each type has distinctive properties which identify it. Changes in direction, forks in a path, slight deviations, starlike clusters, beadlike tracks — all these tell their story. It is also possible to calculate the mass, momentum, energy and other characteristics of the particles involved.

Nowadays accelerated particles are generally hurled at a bubble chamber containing the target (such as liquid hydrogen, at sub-zero temperatures). When the accelerated particles strike the target, they leave visible records of the collision.

So far about 30 different subatomic particles have been discovered. The picture they present is very puzzling in many ways, but physicists believe that eventually some unifying theory will bring them together into a related whole.

In 1937 Carl D. Anderson discovered the *meson*, which may have either a positive or negative charge.There are two kinds of mesons. Pi-mesons weigh 276 times more than an electron and last for 1/200,000,000th of a second. Pi-mesons decay radioactively into mu-mesons, which weigh 212 times as much as electrons; they last 2/1,000,000ths of a second and then decay into high-energy electrons. Mesons are thought to originate from collisions of cosmic rays and gamma rays with various particles.

The interesting thing about mesons is that some physicists believe that these particles are the "glue" that supplies the "binding force" to

A bubble-chamber photograph of what happens after an anti-proton enters at top, moves downward and collides with a proton, forming a neutron (which leaves no tracks) and an anti-neutron, which in turn collides with a carbon atom and is annihilated, with pi-mesons dashing off in several directions as a result of the second collision.

hold the atomic nucleus together. If true, this would indicate that mesons are charged with enormous energies. We can realize this from the following considerations:

Since protons are all positively charged, they should normally repel each other. It has been calculated that if a gram (a fraction of an

ounce) of protons were placed at the North Pole and another gram of protons at the South Pole, the groups would repel each other with a force of 26 tons. Consequently the binding force that holds the protons together in the nucleus must be incomparably more powerful. Incidentally, the tremendous energies liberated in the splitting of an atom are only a small part of this binding force.

In 1942 Anderson discovered another puzzling particle, the *positron*. This is a positively charged electron.

Positrons are formed by collisions of cosmic rays or gamma rays with atoms, and also by the bombardment of atoms by particles. A positron lasts for 1 billionth of a second, until it is disintegrated by collision with a (negative) electron to which it is attracted. The new collision results in the emission of gamma rays or X-rays.

Neutrinos are electrically neutral. They have practically no weight, and are tinier than electrons. The neutrino may also be involved in the binding force, and it has been conjectured that it plays a role in some losses of energy that take place when an atom breaks down radioactively.

The existence of the neutrino was verified in 1956 by a group of scientists of the Los Alamos (New Mexico) Scientific Laboratory. The neutrino's existence had long been suggested by theoretical physicists to account for the disappearance of energy in the radioactive decay of beta particles. But how does one go about trapping a particle that can penetrate through billions of miles of solid matter?

The detector used by the scientists was a liquid scintillation system built on the same principle as the scintillation detector employed in uranium prospecting. Cadmium salts were dissolved in a tank containing 100 gallons of water. The equipment was placed underground at the Savannah River, South Carolina, atomic plant to catch emissions from a large nuclear reactor. The scintillation system was made up of 1,000 gallons of a sensitive liquid and 330 tubes acting as photoelectric eyes.

Elaborate as this equipment was, it was only able to register the passage of a few neutrinos per hour, although billions must have passed through it each second.

Most puzzling of all, perhaps, is the *anti-proton*, a form of antimatter. In 1955 scientists at the University of California photographed an atomic collision that lasted 100 sextillionths of a second. Protons were circulated in the bevatron until they reached an energy of 6.2 billion electron volts and were then hurled at the nuclei of copper atoms.

In this collision, energies of some 2 billion electron volts were expended to form pairs of protons, one of which was positive and the other negative ("anti-protons"). The anti-protons were then forced by magnetic fields into a separate beam directed toward a photographic emulsion. When the anti-protons struck positive protons in the nuclei of the silver or bromine atoms of the emulsion, the result was a very brief but incredibly powerful crash that gave off 2,300 times more energy than is given off on a comparable scale in atomic fission. Brief as the impact was, it left a trace in the form of a "star" on the emulsion.

What we have here is a case of energy being converted into matter and anti-matter, which were in turn reconverted into energy. Dr. Ernest O. Lawrence described this discovery as "a major fundamental achievement in physics," although it will take years to fully appraise its meaning.

Since the anti-proton annihilates matter, it could theoretically be the most destructive force in the world if it could be produced in large enough quantities. However, it takes enormous effort and preparation to produce even the tiniest amount of anti-protons.

The technician controls the operation of the giant magnets which are used to keep the particle beams on their circular path in the cyclotron.

Since 1955 the production of anti-protons with the aid of the bevatron has been going on fairly consistently, generally leading to collisions with protons or neutrons and their mutual annihilation into energy and neutrinos.

But in 1958, with the bubble chamber filled with liquid propane almost at the boiling point, the collision of proton and anti-proton resulted in production of a neutron and an *anti-neutron*. These leave no perceptible tracks because they are electrically neutral. As scientists reconstructed what happened, they described the following train of events:

The neutron escaped. The anti-neutron struck a carbon atom in the propane, and the resulting smash-up of the atom left a star-pattern of pi-mesons.

It is now theoretically possible to create an anti-atom with a negatively charged nucleus made up of anti-protons and anti-neutrons, with anti-electrons (positrons) revolving about them. And it may be that galaxies of anti-matter exist far off in space, accounting for mysterious radio signals that have so far baffled astronomers.

Such speculations have led some students to wonder about the possible existence of anti-gravity. This seems outlandish to us, but in 1900 the discoveries of X-rays, radioactivity, and the electron seemed equally grotesque to the people of that day. Some Russian scientists have suggested that if there is such a force as anti-gravity, or if it can be created, it would be possible to build an airplane that would be unaffected by gravity. But these are speculations that range into the remote future.

ACCELERATORS IN MEDICINE AND RESEARCH

The accelerating process imparts to the propelled particles energies that are on a par with the radioactive power of 100 grams of radium. As there are only 1,500 grams of radium in the whole world, accelerators will very likely gradually take over the role of radium in cancer treatment.

Remarkable studies based on brain irradiation with high-speed particles from the cyclotron have been made at the Radiation Laboratory at the University of California. These studies indicate that the hypothalamus is the master-control region of the brain, using the pituitary gland as a messenger to call for the production of hormones by other glands.

The goal to which these studies are directed is the cure of such diseases as arthritis, diabetes, hypertension, and thyroid ailments by

irradiating the hypothalamus and thus controlling the production of hormones.

An important use of particle accelerators has been the experimental production of radioactive isotopes which have proved their immense value in many fields. But since these are prepared for practical use as by-products of nuclear fission, they will be described in the next chapter.

7. Radioisotopes and Atomic Energy

Within twelve years of their introduction into general use, radioisotopes were being employed to treat more than one million patients annually, and in all their various applications were saving United States industry over half a billion dollars a year. It is estimated that by 1960 the annual savings will amount to ten times that amount. Over a thousand radioisotopes have been discovered, and new ways of using them turn up daily.

THE DEVELOPMENT OF RADIOISOTOPES

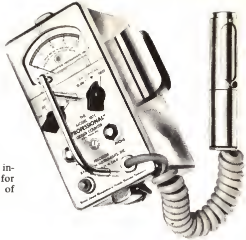
Many elements which are not radioactive have radioactive isotopes. This seems extremely strange until we realize that a large number of these radioisotopes are so unstable and decay so rapidly that they are never encountered in the natural state. In fact, it was not until 1934 that scientists realized that they could create radioactive isotopes by means of atomic bombardment.

In 1934 Frederic Joliot-Curie and his wife Irene Curie bombarded aluminum atoms with alpha particles (helium nuclei). To their amazement, the phosphorus that was produced by transmutation was radioactive and so unstable that in less than three minutes it was converted into another element, silicon.

It did not take scientists long to see the many uses to which radioactive isotopes could be put. In most cases the amount of radiation emitted is negligible and brief enough to be harmless — actually a source of great benefit.

Radiation can be detected and measured by various instruments, which, in brief summary, work like this:

A gas — generally argon — is forced into a container which has positive and negative electrodes. If any radiation is being discharged within the instrument's detection range, it imparts an electrical charge to the gas atoms — it ionizes them. The positive ions pass to the negative electrode, while the negative ions pass to the positive elec-



The Geiger counter is the instrument generally used for registering the presence of radiation.

trode. The electrical impulses, which may be as frequent as one-trillionth of a second, are registered on the counter.

The most popular of these instruments is the Geiger counter. It has a tube which functions as the negative electrode, while a wire inside acts as the positive electrode. The necessary voltage comes from a battery, and a meter is attached to indicate that ionization is taking place.

As positive ions stream to the wall of the tube, and negative ions pass to the wire, the pulses are registered either by a needle moving on a dial or by the movements of a mechanical counter.

The earliest discoveries of radioisotopes were made in the laboratory, and then in particle accelerators. Today they are regularly prepared in usable quantities in nuclear reactors.

RADIOISOTOPES IN MEDICINE *

From the start, radioisotopes have played an important part in cancer treatment and research. Phosphorus 32, for example, is being used to make highly accurate diagnoses of cancer of the stomach and esophagus. (Note, by the way, that the names of isotopes are usually followed by their atomic weight, to show that we are referring to an isotope and not the common form of the element.)

* For more information about radioisotopes and atomic energy, see Reinfeld: *Uranium and the Other Miracle Metals.*

The tracer element is used with Geiger counters small enough to be swallowed. Where cancer is present, the radioactive count of the swallowed "tracer" phosphorus is much higher than normal. Cancer of other parts of the body can also be diagnosed with radioisotopes.

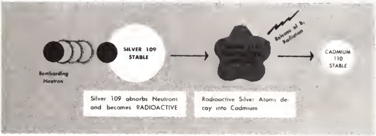
In cases of brain tumors, radioactive boron is administered, as it has an affinity for cancer cells. The patient is placed near a special opening of a nuclear reactor and only the malignant area remains unshielded. The reactor emits billions of neutrons in a very short time. These neutrons are absorbed by the boron atoms and the resulting intense radioactivity kills diseased cells.

Radioactive manganese has been used successfully to destroy liver cancers in laboratory animals. This may prove of great value, as cancer of the liver is inoperable. The radioactive material, which has a special affinity for the liver and pancreas, is enclosed in a complex organic molecule and, when administered, rapidly finds its way to the diseased areas.

At the Francis Delafield Hospital in New York, a research group has built a robot with a glass heart, lungs and kidneys. Known as a "cytogenerator," this robot has kept cancer cells alive for 30 days. This has enabled scientists to study the diet and other characteristics of cancer cells by using isotopic tracers.

A new science called "autoradiography" harks back to Becquerel's discovery of radioactivity. It involves the technique of administering traces of a radioactive element to a living system — a laboratory animal or cells in tissue culture.

Later on, tissue samples are exposed to a photographic emulsion so that an image is formed on the film. Repeated use of such "self-



When silver is bombarded with neutrons, some silver nuclei absorb a neutron and turn into a radioisotope, silver 110, and release energy in the process. These unstable atoms are in turn converted into a stable form of cadmium.

photographs" yields important information about tissue growth, function and replacement.

This technique has already produced appreciable information about the components of DNA and the composition of the blood.

In order to study the effect of the tranquilizing drug, reserpine, in physiological and biochemical research on animals, it has been prepared in radioactive form. Scientists hope in this way to learn more about how the drug operates in cases of high blood pressure, coronary disease and mental illness.

Reserpine is a white crystalline substance extracted from roots of Rauwolfia serpentina, a shrub found in the Himalayan foothills of India, where the root has been used medicinally for 3,000 years. To get the radioactive effect, the plant was grown in hermetically sealed greenhouses, and radioactive carbon dioxide was injected into the atmosphere.

Soviet scientists have reported remarkable discoveries by using tracer elements in studying electrical and chemical processes in the brain.

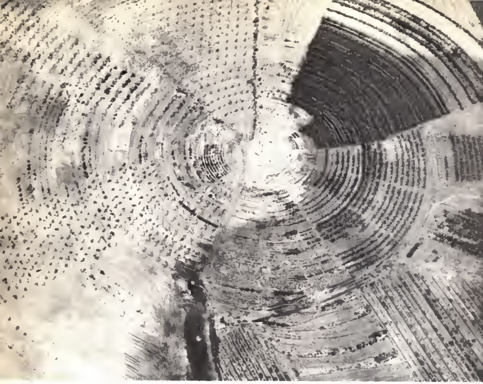
They have found, for example, that even in adult animals the brain undergoes a continuous process of breakdown and renewal. Stimulation, such as violent sensations, results in an immediate increase in the utilization rate of such biochemical substances as proteins, nucleic acids, and phosphorus compounds. Should this renewal rate slow down, the result is drowsiness, sleep, hibernation, or even death.

Continuation of this type of research with tracer elements should add enormously to our knowledge of the chemical basis of brain activity.

Radioiodine, which has been used successfully in treating thyroid cases, has also been administered in an "atomic cocktail" to treat an ailment known as "racing pulse." This is a painful and disabling heart ailment which may result in overtaxing that organ. Radioiodine takes about three months to achieve its maximum effect.

Each year the number of hay-fever sufferers goes up. So far all attempts to eradicate ragweed have been inadequate. In order to find out how far pollen travels, radioactive phosphorus is being injected into ragweed plants. Once this has been ascertained, scientists will have the basis for a really effective anti-ragweed campaign. The amount of radioactive material which enters the atmosphere this way is much too small to have any harmful effect.

An interesting recent development is an X-ray machine which operates without electricity. It is called an "isotope diagnostic machine," and it is quite small and simple as well as easily portable.



Aerial view of the gamma field at Brookhaven National Laboratory, where plants are subjected to gamma radiation in order to develop improved strains of plants through mutation. Darkened areas have been irrigated.

This device has an underside in which an opening can be made by moving a plunger. The object to be X-rayed is placed under a disk, the aperture is opened and the target exposed to X-rays from a radioactive isotope. The immediate use for the machine will be military, but it is certain to have wide application eventually. The films taken with it are not up to the standard of conventional X-ray machines, but they are sure to be improved.

RADIOISOTOPES IN AGRICULTURE

One of the most exciting fields of radioisotope research is agricultural research: the irradiation of plants with X-rays, gamma rays,

beta particles, neutrons and ultraviolet rays. The purpose of this is to cause mutations in the plants by creating hardier varieties that can fight off destructive mildew, blight and rust. Barley, peas and beans have already been improved by irradiation techniques.

At Brookhaven National Laboratory there is a carefully sealed-off garden in which plants are irradiated daily with cobalt 60. Whereas a random sample of corn might show one mutation in 3,000 kernels, the Brookhaven corn has one mutation in every ten kernels.

In this outdoor laboratory the evolutionary process is enormously speeded up. Beneficial mutations improve the plant breed; harmfully mutated plants soon die out. It may be, as some scientists have maintained, that all mutations that have aided the evolutionary process have been caused by natural radiation.

Merely to improve the plants is not enough; for plant parasites may also change and still be able to cause a great deal of damage. Brookhaven scientists are therefore studying the effect of radiation on fungi in order to see which ones are most likely to mutate.

A tremendous improvement in living standards for much of the world's population would be possible if there were enough water to irrigate desert areas and reclaim them for raising food. It will take years, but good progress is being made on the problems of de-salting sea water and purifying brackish inland water.

Gamma radiation of a white carnation plant (left) caused a mutation in the middle flower, turning it into a red carnation, and (right) produced a mutated white area on a normally red snapdragon.

A scene in the greenhouse at Brookhaven National Laboratory where plants are exposed to cobalt 60 radiation. When the technicians are in the greenhouse, the radiation source is removed. During the 20 hours a day that the radiation is functioning, it is shielded in such a way that it does not extend beyond the greenhouse.

At present these processes are too expensive to be used on a large scale. There are at least three ways in which atomic science can be employed to make them more efficient and hence cheaper.

One is the use of radioisotopes to chart the course of great underground rivers so that they can be tapped more effectively. Secondly, the energy needed to distill sea water can be supplied more cheaply by substituting a nuclear reactor for conventional sources of power. Finally, the electrolytic process involved can be carried out more economically with radioactive materials.

In at least one remarkable case, insect damage has been fought effectively with a radioisotope. This was done in Florida and adjacent states, where the screwworm fly annually destroyed cattle valued at $10,000,000.

After all orthodox methods of exterminating this pest had been tried and found wanting, a novel approach was finally adopted. Male screwworm flies were exposed to gamma rays from cobalt 60. This made them sterile. They were then dropped on infested areas by low-flying planes. When they mated with the females, there was naturally no offspring.

IRRADIATED FOODS

The purpose of exposing food to radioactive sources is to kill the bacteria that spoil food. Once this is done, the food may be kept for a long time in sealed packages or cans without spoiling. At Brook-

By "tagging" fertilizers with radioactive phosphorus and then exposing the leaves to film, the effectiveness of the fertilizer is observed by noting the distribution of the nutritive substances.

Radiation causes mutations in plants that enable them to resist parasites. The two oat stems at the left are infected with rust fungus, a disease that results in sizable crop losses. The two oat stems at the right have mutated as a result of radiation, and are consequently able to resist the fungus.

haven it has been found that mild radiation has prevented potatoes from sprouting for two years. Other potatoes which were not irradiated soon developed sprouts.

This suggests that the unsold portion of the annual potato crop could be preserved in perfect condition and eventually consumed, instead of being wasted as now happens. Low-level irradiation of potatoes is likely to be the first application of the food-sterilizing process by radiation.

The projected irradiation of meat prior to packaging will likewise bring great advantages. At present, prepackaged meat can be kept in refrigerated counters for three days at most without spoiling. Irradiating the meat would extend the period as much as three weeks. Research has shown that pork can be purified of any trichinosis danger by radiation with a radioactive cobalt isotope.

Experiments at the U. S. Army Radiation Sterilization Office in Chicago have revealed that in some cases irradiated food can be kept for months without harm. Unfortunately, complete sterilization creates problems of taste and odor. Professor L. E. Brownell, who heads the University of Michigan's Fission Products Laboratory, has said of sterilized meat that it "smells like a dog when it comes in after rain. And it tastes like it smells."

High radiation gives milk a garlic taste and odor. Butter looks like lard and takes on a rancid taste. Low-level radiation, giving comparatively limited protection, seems the best compromise.

The Stanford Research Institute in Palo Alto, California, has shown that peas, carrots, broccoli and other fresh vegetables can be preserved by radiation. It has also worked on the problem of eliminating mold on oranges to extend their storage time.

Grain irradiation is another very important facet of food preservation, as a tremendous part of grain crops is lost through damage from insects. Bernard Proctor, head of the food department at Massachusetts Institute of Technology, has summed up the research findings in these words:

"We have found that a relatively small radiation dose can be used to kill all known insects that attack cereal grains. Such treatment can be accomplished by passing the grain under an electron beam. The speed of the belt can be regulated so that the grain will receive the proper dose to kill adult insects, eggs, larvae or pupal forms."

Radiation does not affect the quality of milled flour. Adding radiation to the milling process would cost far less than a penny a pound. With other foods the cost varies — anywhere up to six cents a pound.

Before any kind of food radiation can be adopted in the U. S., it will have to have the approval of the Food and Drug Administration. Naturally this approval will not be given until the most stringent tests have made it clear beyond any doubt that irradiated food is just as wholesome as untreated food.

There are two ways of irradiating food. One is to use some highly radioactive material, such as the waste products of a nuclear reactor. In the University of Michigan laboratory, food is packed in a concrete cellar above a pool of water containing the radioactive source. By remote control the radioactive cylinder is raised to the surface and allowed to act on the food. In commercial processing, it would of course be more efficient to have the food loaded on a conveyor that would move it through a concrete radiation chamber.

The second method is to use a radiation-generating machine which works on the principle of an X-ray machine. The amount of time required for radiation varies with the nature of the radiation source. A powerful beam may need only a few minutes, while low-level radiation may take as much as 24 hours.

Research has shown that protein is not affected by radiation. Of all the vitamins, only Vitamin C is affected, but this may be avoided by using a food additive that will protect the vitamin.

Injections of radioisotopes enable scientists to improve the diet of cattle. This is part of a University of Tennessee research program sponsored by the Atomic Energy Commission.

THERMOELECTRIC RADIOISOTOPES

Thermoelectric materials have the property of converting heat into electricity. Certain kinds of ceramics, similar to those used in chinaware, have been found to possess this property. Requiring no special installation or any movable parts, they furnish a portable and convenient source of electricity.

The ceramics can be used in pellet or powder form. Various sources of heat are suitable — coal, atomic reactors, bottled gas, or radioactive isotopes. Of these sources, the isotopes seem to have the greatest all-round advantages.

Suggested uses include powering transmitters in satellites, and having emergency-power units at hand in hospitals and in the home in the event of power failure.

An atomic battery no larger than a man's shirt button, that can run for five years without refueling, is expected to have wide uses — for instance, to provide power for hearing aids, miniature radios and civil-defense warning receivers. Eventually it may be used for wrist watches.

The battery operates by converting radioactive energy into electrical energy, and is fueled with promethium 147 — a radioisotope of an element so rare that its chief source is atomic wastes. Consequently the battery is likely to be expensive.

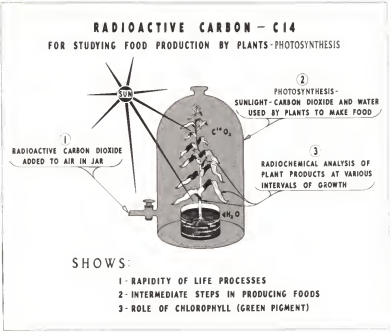
Radioactive strontium can also be used to power a battery — for operating a telegraph relay or telephone transmitter, for example.

OTHER USES OF RADIOISOTOPES

Scientists are able to obtain accurate information about primitive man, prehistoric animals, the age of the earth, climatic conditions in former times, and the like, from studying radioactive substances which take thousands — in some cases, even billions — of years to decay.

Carbon 14, which is the basis of one such dating process, has a half-life of 5,600 years. It takes about 25,000 years for practically all of its radioactivity to decay. This isotope is formed by the activity

To determine the durability of their tires, manufacturers use radioisotopes to check the rate of wear in the tread.



of cosmic rays that collide with atoms in the earth's atmosphere and break them down.

The neutrons released in this way bombard nitrogen atoms (atomic weight 14, made up of 7 protons and 7 neutrons). The nitrogen atoms lose a proton and gain a neutron, turning into carbon 14 (atomic weight 14, made up of 6 protons and 8 neutrons). This isotope differs from the common form of carbon (atomic weight 12, made up of 6 protons and 6 neutrons).

All living things take in minute amounts of carbon 14, which is present in the atmosphere in the ratio of one part to every trillion of ordinary carbon. After death, carbon 14 keeps decaying at a constant rate. The scientist takes a sample of the substance being tested, reduces it to carbon dioxide and then to carbon. Using a Geiger counter or similar instrument, he determines the age of the sample from the amount of radiation. Later refinements in technique have increased the range of this process to well over 40,000 years.

Another use of carbon 14 is as a tracer in studying cellulose in all its phases. The radioactive carbon is injected into young pine trees. Later on in the laboratory, the progress of the tagged cellulose can

be examined in such end-products as rayon tire-cord, lacquers, sponges, film and textiles. The conservation programs of the United States and Canada are also expected to gain from the increased scientific knowledge of the details of tree growth.

Radioisotopes are often used to check the desired thinness of paper, plastic or metal products. The finished sheet passes under radiation which is measured by a radiation counter below. If there are any thick or thin spots in the sheet, the amount of radiation that has passed through will reveal the discrepancy.

In shipping oil over long-distance pipe lines, different kinds and grades are pumped in, one after another. By marking off the various shipments with a small quantity of radioactive oil at the transmitting station, all confusion is avoided. The receiving station is equipped with radiation counters and at the proper time the shipments can be kept apart and shifted to the right storage tanks.

FUTURE USES OF RADIOISOTOPES

Widespread research with radioisotopes indicates that new uses are constantly being developed. Here are some applications that still lie in the future:

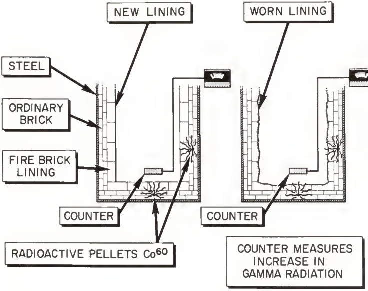
Columbia University chemists are working on a project to transmute coal into synthetic natural gas consisting largely of methane. This involves the use of a 20-pound block of cobalt 60 to break down the coal chemically by applying heat and pressure in the presence of the radioactive cobalt. If it becomes feasible to produce the synthetic gas, the artificial product would be much more efficient than the "water gas" which is at present derived from coal.

An atomic wrist watch is one of the projects at the RCA Research Center at Princeton, New Jersey. Although many of the details have been worked out, it is doubtful whether such a watch will be practicable before 1975.

The atomic watch will be far more accurate than present-day timepieces; it will be silent, and it will last for more than a lifetime. Basically, it will have three elements: a nuclear battery, a timekeeping element to provide 60 electronic pulses a minute, and a luminous screen to indicate the time. (The watch will have no hands.)

As envisaged now, the nuclear battery will be made up of a tiny layer of radioactive strontium and a mechanism that produces electricity when exposed to radiation. (In time, some more efficient radioactive material will be discovered. In any event, the amount of radioactivity will be well below the safety margin.)

Though the battery will be no larger than a pencil eraser and will



RADIOACTIVITY MEASURES WEAR OF FIRE BRICK LINING

work on a few millionths of a watt, it will operate for a century at least. There will be an electronic pushbutton for resetting the time dial if required.

Atom-powered vacuum cleaners are promised by 1965. They will probably use a miniature computer, operating with a magnetic memory. The pattern of the room would be recorded on tape, leaving the housewife nothing to do besides setting a dial and pressing a button.

Another advance in modern living is a radioactive golf ball which can be recovered quickly when it goes into the rough. When a trial ball was made radioactive with cobalt 60, a blindfolded caddy had no trouble finding it with the aid of a Geiger counter. However, it will take some time before the present price of $20 comes down.

Some of England's most famous historical relics are menaced by the deathwatch beetle which attacks wooden beams. (It gets its strange name from the peculiar tappings with which it operates.) One of the great nuclear physicists of our time, Sir John Cockcroft, has suggested that the timbers of Westminster Abbey, St. Paul's Cathedral, and hundreds of other famous relics could be saved by subjecting them to low radiation that would make the beetles infertile.

The use of radioactive isotopes has become so general that the

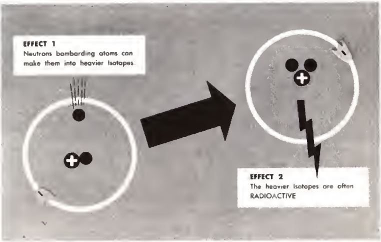
U. S. Atomic Energy Commission is beginning to entrust their preparation to commercial facilities. It has been said that radioactive isotopes are destined to equal the microscope in importance. We may yet find that even this daring claim is an understatement.

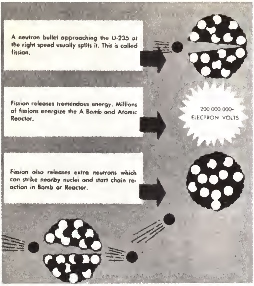
NUCLEAR FISSION

The discovery of the neutron in 1932 gave powerful impetus to experiments involving the bombardment of atoms. Uranium became the favorite target, and neutrons the favorite missile. Uranium was favored because it has the most unstable nucleus of all the natural elements. Neutrons had the advantage of being electrically neutral, so that they would not be attracted or repelled by electrical forces inside the atom.

Enrico Fermi was one of the pioneers in the use of this technique. He was the first to realize that if the neutron's normal speed (anywhere from 5,000 to 10,000 miles per second) were slowed down, its chances of being absorbed by a uranium atom which it happened to strike, were greatly increased.

In the late 1930's scientists began to use "moderators" to slow down the neutrons. The best moderators are atoms of light elements; when neutrons collide with these atoms, they are slowed down considerably without bouncing off violently. Hydrogen, we know, is the lightest element, and "heavy water" (water containing the hydrogen isotope which has an atomic weight of 2 instead of 1) became a





The chart illustrates the three aspects of nuclear fission: the splitting of the uranium 235 atom by a neutron, the release of an enormous amount of energy, and the release of extra neutrons which split more uranium atoms and thus maintain a "chain reaction."

favorite moderator. Another was graphite, which is a form of carbon, also one of the lighter elements. (Graphite was used as a moderator in the first nuclear reactor, successfully tested by Fermi in December, 1942.)

Fermi made another important discovery but failed to realize its portentous consequences. Using fast neutrons to bombard uranium, he obtained an isotope, uranium 239, which quickly turned into another element, neptunium, with the same atomic weight. Had he followed up the experiment, he would have learned that neptunium turns into plutonium (still with the same atomic weight), after 52 hours. In 1940 two American scientists followed through to this ultimate conclusion (page 151), making a discovery of the first magnitude.

The accidental outcome of Fermi's experiment was followed by an even more amazing accident. Otto Hahn repeated Fermi's experiment, but what happened was that two new elements (barium, atomic number 56, and krypton, atomic number 36), appeared while a great deal of energy was emitted in the form of heat, visible light, and gamma rays. Hahn was baffled; nothing like this had ever happened in the history of science.

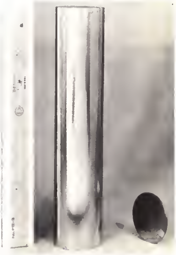
Lise Meitner, a distinguished physicist and a former colleague of Hahn, learned of the experiment and interpreted its true meaning. When she fled from Germany to forestall arrest by the Nazis, she

turned over her secret to American scientists. (This secret was the basis of the atomic bomb.) Intense research followed — by some of the world's greatest scientists, at a cost of billions of dollars. We can summarize the results in this way:

In 1905, Albert Einstein had announced his famous equation: $E=mc^2$. Matter, he had declared, could be converted into energy and vice versa. In the equation, he stated that the amount of energy that can be liberated from matter equals its mass multiplied by the velocity of light. *But this applies only if the binding force that holds the atomic nucleus together can be freed.*

An ordinary explosion gives off tremendous energy, but the atoms are not disintegrated. This explains why the liberation of the binding force in an atomic explosion emits 400 million times more energy than a cannon shot. This splitting of the uranium atom, or "nuclear fission," as it is termed more precisely, does not occur with the common form of uranium (uranium 238) but only with its isotope, uranium 235.

But uranium 235 is fairly rare. In any sample quantity of uranium there are 139 parts of uranium 238 to one part of uranium 235. Hahn was the first scientist to bring about nuclear fission (of uranium 235); but because this had never been observed and because he did not expect it to happen, he was baffled. (Note that the atomic numbers of the two new elements at the end of his experiment had atomic



The twenty-pound bar of uranium at the left is made up of 99.3 per cent uranium 238 and 0.7 per cent uranium 235. The sliver-thin disk at the right represents the amount of uranium 235 contained in the bar.

numbers adding up to 92, the atomic number of uranium. In other words, the number of protons was still the same, but they were now distributed over two new elements. This is what we mean by nuclear fission.)

The first question that had to be answered after Professor Meitner's revelation was this: were all, or only some forms of uranium fissionable? The answer was discouraging: uranium 235, the rare form, was fissionable; uranium 238, the comparatively plentiful form, was not fissionable. This created the practical problem of obtaining enough uranium 235 to construct a bomb.

The working principle of the bomb was the "chain reaction." As uranium 235 absorbed neutrons, it fissioned and in the process gave off more neutrons. The new neutrons were absorbed by more uranium atoms, which kept fissioning. If the right amount of uranium — the "critical mass" — were supplied to begin with, an explosion of previously unrealized power would take place in a millionth of a second.

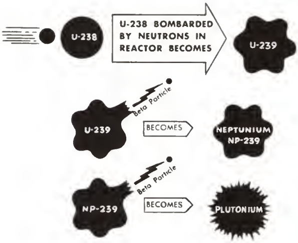
Intensive research was essential to discover ways of separating uranium 235 from uranium 238. Eventually four ways — all very ingenious, very elaborate, and very costly — were devised. The four methods were electromagnetic separation, centrifugal pressure, gaseous diffusion, and thermal diffusion.* Gaseous diffusion was finally selected as the most practical, and a three-billion-dollar plant was constructed at Oak Ridge, Tennessee.

In the course of research it was learned that plutonium is also fissionable and can therefore, like uranium 235, be used as the basic material of a bomb. Plutonium can be made in a nuclear reactor, with uranium as the "fuel." Of course, in a reactor the desired process is the opposite of making a workable bomb. It is desirable that neutrons be absorbed fast enough to keep the chain reaction going; if they are absorbed too slowly, the chain reaction will die out. On the other hand, if the neutrons should get absorbed too rapidly, the chain reaction might very well get out of hand and lead to an explosion.

To avert this danger, control rods are provided in the reactor. They are made of materials, such as boron or cadmium, which have a high rate of neutron absorption. If the neutrons are being absorbed too rapidly by the uranium atoms, enough control rods are inserted to slow down the chain reaction; if not enough neutrons are being absorbed by the uranium atoms, some control rods are withdrawn.

Theoretically, plutonium production in a nuclear reactor is simply a mass-production form of the laboratory method of obtaining minus-

* For the details of these processes, see Reinfeld: *Uranium and Other Miracle Metals.*



cule quantities of plutonium. The uranium 238 in the reactor absorbs neutrons and turns successively into uranium 239, neptunium, and plutonium.

In actual practice, the process is anything but simple. All the substances involved are highly radioactive and must be handled by remote control with elaborate safety precautions. The plutonium as it comes from the reactor is mixed with about 35 substances spread over some 300 isotopes; most of these are radioactive with a half-life that in some cases lasts for years. The plutonium has to be separated from the other substances in a long series of laborious processes. When the plutonium is finally obtained, it has to be coated with a special substance that absorbs neutrons and thus prevents a new reaction from starting.

THE ATOMIC BOMB

The critical mass for an atomic bomb — the amount of uranium or plutonium needed to keep fission going on — is somewhere between 2 and 200 pounds. Two masses of atomic "fuel," each smaller than the critical mass, are kept apart and shielded from each other. At the desired moment a timing mechanism rips away all impediments and forces the two masses together, causing an explosion in a few millionths of a second.

The only photograph made during the construction of the world's first nuclear reactor. The work was supervised by a team of scientists under the direction of Enrico Fermi and produced a successful chain reaction on the historic date of December 2, 1942.

An atom bomb can also be exploded by radar. In this case, signals from a distance cause compressed air to force neutrons toward the mass at the same time that a radioactive gas is also forced toward the

mass. The reaction time and the strength of the resulting explosion are the same as with the first method. Temperatures of 100 million degrees Fahrenheit may be reached.

The resulting explosion is destructive in three ways. In the first place, the explosion creates shock waves that move outward in all directions and topple over buildings with their violent pressure.

Secondly, the enormous heat of the explosion causes nearby air currents to expand and rush off, creating a vacuum in the center of the blast. This sucks in surrounding air, pushing over buildings in the opposite direction from the previous pressure.

Third, there is the toll of human lives — from falling wreckage, from severe burns, from the penetrating gamma radiation.

ATOMIC ENERGY

Nuclear fission of a pound of uranium 235 produces as much energy as 1,350 tons of coal or 200,000 gallons of gasoline. Prodigious as this liberation of energy is, nuclear fission actually represents the freeing of only 1/1175th of the binding force that holds the atomic nucleus together. If *all* that energy could be released, the results would be fantastic. For example, a small lump of snow contains enough energy to heat a large apartment house for a year. A cup of water contains enough energy to run a 100,000-watt generating station for a year.

The thoughts of scientists have naturally turned to using this energy to generate electric power. As billions of neutrons and atomic targets collide every second, the kinetic energy is converted into heat energy. This heat can be used to make steam for driving turbines to power electric generators.

More than 50 different kinds of nuclear reactors have been designed. They are all masterpieces of scientific research and engineering skill, and each one serves some special need.

As we have seen, the continuity of the chain reaction depends on an adequate supply of neutrons. An average of 2.5 neutrons is produced by each fissioning atom. One of these neutrons is needed to keep the chain reaction going in the uranium. How much of the remaining 1.5 neutrons is wasted will determine the efficiency of the nuclear reactor.

The most efficient type of reactor is the "breeder," so called because as the reaction goes on, the number of available neutrons actually increases. As originally designed, the breeder used natural uranium (139 parts of uranium 238 for one part of uranium 235). The fissioning uranium 235 atoms produce 2.5 neutrons as in other reactors. But there are a number of differences.

The great gaseous-diffusion plant for separating uranium 235 from uranium 238 was built by the United States government at Oak Ridge, Tennessee, during World War II. It is the largest continuous-process plant in the world.

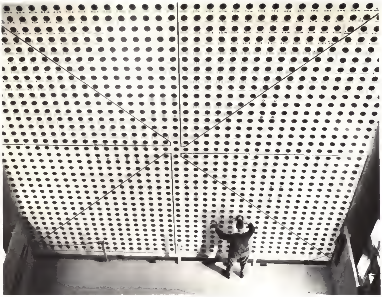
In the first place, the core of uranium is very small — about the size of a football. No moderator is needed, and thus a certain amount of wasteful absorption of neutrons is avoided. The reactor is surrounded by a "blanket" of uranium 238 which catches stray neutrons. Because of these special design features, about 1.1 neutrons are available for transmuting the uranium 238 in the core into plutonium. This works out to produce roughly 15 pounds of plutonium for every 14 pounds of uranium 235 that are consumed.

An additional advantage is that as plutonium atoms fission, they release an average of 3 neutrons. This increases the efficiency of the reactor still more. If it is desirable to slow down the reaction, this can

be done by moving the uranium blanket. The heat is carried off by a liquid alloy of sodium and potassium.

A clever adaptation of the breeder is used at the British nuclear installation in Harwell. This reactor uses a core of uranium 238 and plutonium. As the plutonium fissions, each split atom releases three or

This view of the nuclear reactor at Brookhaven National Laboratory shows the complicated research equipment which is used with beams of neutrons that emerge from holes in the side of the reactor.



Ten tons of pure uranium, made up of slugs loaded individually into separate holes, are used as the "fuel" for the nuclear reactor at Brookhaven National Laboratory. Other substances can also be inserted in order to make them radioactive. The technician in the picture is protected by a five-foot-thick concrete wall, and he uses a periscope to view the handling of the radioactive materials by remote control.

more neutrons. One of these fissions another plutonium atom, while two or more freed neutrons transmute the uranium 238 into plutonium. Thus, the quantity of plutonium keeps doubling all the time.

NUCLEAR POWER PLANTS

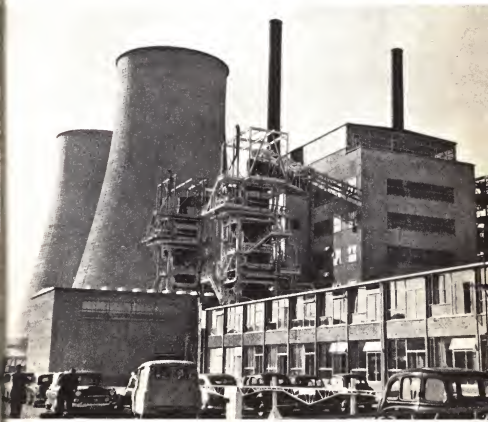
Because electric power is cheaper in the United States than anywhere else in the world, it will take many years before the price of electricity generated from nuclear plants can compete with the price of electricity from conventional sources. The average cost of conventionally generated electricity in the United States is about 6 mills per kilowatt hour. The cost of electricity originating from British atomic plants is about 9 mills per kilowatt hour — a very good figure, which is sure to be reduced as more efficient methods are developed.

The first American full-scale nuclear power plant for purely civilian purposes was opened for operation in 1958 at Shippingport, Pennsylvania. It is a joint project of the Westinghouse Electric Corporation,

the Duquesne Light Company, and the Atomic Energy Commission. Constructed at a cost of over \$100,000,000, it will eventually have a capacity of 100,000 kilowatts — enough to supply the power needs of a city of 200,000 people. The reactor operates with a 12-ton core of uranium that costs \$18,000,000 and lasts between two and three years.

The cost of power from the Shippingport reactor is 64 mills per kilowatt hour, and it will therefore operate at a considerable loss. The pressurized water reactor used here was originally intended for another purpose, and it is by no means the most efficient type of reactor for producing electricity. However, the experience gained from the planning, construction and operation of this plant will be put to good use on future projects.

The great nuclear power plant at Calder Hall, which started operations in March 1956, was primarily designed for producing plutonium. It also produces electric power for commercial use, and was the world's first plant to be operated for this purpose.



The Argonne National Laboratory has designed this "slave-robot" which is to be manipulated by remote control for repair and handling operations which involve radioactive equipment. The operator is of course protected by heavy shielding and well removed from the radioactive source.

England has completed three large-scale nuclear plants, to which nine more are to be added and in operation by 1965. In Britain the need for new sources of power has become acute for a variety of reasons: the gradual exhaustion of its coal mines, the uncertainties of obtaining oil from the Middle East, and the cost of shipping fuel to the British Isles.

ATOMIC-POWERED VESSELS AND SPACESHIPS

The successful operation of the first atomic submarine, the *U.S.S. Nautilus,* created keen interest in the idea of using atomic power for commercial shipping as well. Such vessels will be expensive, but there will be offsetting gains: greater speed, economy of operation, space saving for additional cargo.

The fuel cost of an atomic ship would be less than half that of an oil-powered vessel; and an atomic ship should be able to circumnavigate the globe without refueling. With no space needed for smokestacks, fuel storage, flues, etc., there will be room for considerably more cargo.

On completion in 1960, the *N.S.* (Nuclear Ship) *Savannah,* being built by the U. S., will set out on a series of round-the-world tests and goodwill tours. It will be 600 feet long and will carry a hundred passengers and 12,500 tons of cargo. Built at a cost of $42,500,000, the vessel embodies the most advanced principles of design, speed and efficiency; in addition, it will have all the luxurious appointments of a modern liner. It is estimated that the *Savannah* will be able to travel 350,000 miles in three and a half years on only a single change of nuclear fuel.

The Mitsubishi Heavy Industries Company of Japan has announced plans to construct an underwater oil tanker to be powered by a nuclear reactor. The tanker will have a 30,000-ton displacement and will travel at 22 knots. It will be able to remain submerged for a month if necessary. As an undersurface craft it will be able to avoid the frequent storms that trouble surface vessels in the Pacific.

Nuclear submarines are at present capable of travelling between 20 and 30 knots. By 1970 later models will have attained a speed of 60 knots, and even 100 knots is considered an eventual possibility.

Submarine cargo carriers that are guided from a distance, like missiles, are another likely development. These vessels would have to be manned only when leaving or entering a harbor.

Considerable research is going on to develop nuclear-powered rocket engines. Such engines would have two to three times the thrust of the most powerful chemical-fueled missile and are expected to lift

ten-ton spaceships far beyond the earth's atmosphere. The nuclear reactors for this purpose will have the additional advantage of weighing much less than conventional fuels.

Several propellants are being considered, including hydrogen, helium and rubidium. It is estimated that speeds of 6,000 miles per hour could be attained. Although the fuel will be small enough to fit into a woman's handbag, enough radiation will be emitted to create serious problems — how to protect the passengers, and how to avoid contaminating launching and landing sites.

PEACEFUL BOMBS

Scientists have suggested that underground atomic explosions in strategic places could serve many valuable purposes. (Underground explosions reduce radiation hazards to a minimum.)

The oil industry could use explosions to break up oil strata that cannot be reached at present. Many mining operations would benefit from the same procedure. Inconvenient natural barriers could be destroyed; harbors could be improved. In desert regions, such explosions would bring underlying streams to the surface, so that the arid wastes could be reclaimed.

ATOMIC AUTOMOBILES?

Atomic power for present-type automobiles is out of the question in the foreseeable future, because the atomic equipment would be too heavy and bulky. The need for adequate shielding complicates the problem still further.

But it seems possible to design "land trains" that would be powered by a 40-ton nuclear reactor. They could travel for 30,000 miles without refueling, and would be particularly useful in deserted areas which have few roads. These huge trailer-trucks would be equipped with enormous rubber tires, enabling them to travel on roadless terrain.

NUCLEAR SUBMARINES

The United States now has eight atom-powered submarines, of which the *Nautilus* was the first. More than half of the *Nautilus*' 300-foot length is taken up by the nuclear reactor and other equipment which drives it along at a speed of 20–25 knots, with a cruising range of 30,000 miles without refueling. Its underwater cruising speed is faster than its surface speed.

The latest of the atomic submarines, the *Triton*, is the largest to date, with a length of 447 feet and a displacement of 8,000 tons. It has been designed for more speed on the surface (25–30 knots) than

underwater (17–18). To get the increased speed, the *Triton* employs two nuclear reactors; this gives it a cruising range of 112,000 miles without refueling. It has three decks and an elaborate array of radar equipment.

The United States Navy has perfected a nuclear depth charge which is much more destructive than conventional depth charges. It is believed to operate efficiently within an area of a square mile. Polaris, a rocket with a thermonuclear warhead and a range of 500–1,500 miles, is designed to be launched from a submarine submerged at considerable depths.

An atomic plane carrier of the U. S. Navy, which is scheduled to be completed in 1962 at an estimated cost of $325,000,000, will have eight nuclear reactors, two for each propeller shaft. A light cruiser, equipped with four nuclear reactors and designed for launching guided missiles, is expected to be completed in 1961.

ATOMIC PLANES

The cost of constructing an atom-powered plane is estimated at half a billion dollars. Present plans give 1965 as the earliest year in which atom-powered planes could be manufactured in the United States in any quantity.

An atomic plane would have a tremendous range, as it could fly for days without refueling. At present the chief difficulty is in devising shielding that will adequately protect the crew against radiation. Among the important uses of atomic planes would be the following:

By taking over the North Polar patrol, they would be able to flash warnings of enemy attack sooner than can be done at present.

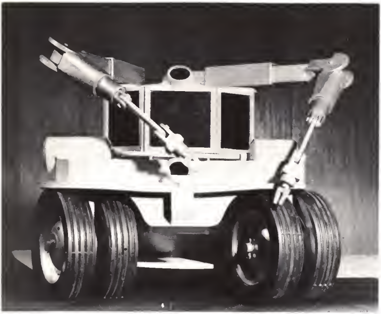
An atomic seaplane could do an effective job hunting for surface vessels and submarines. It would be equipped with nuclear depth charges, air-to-surface missiles and air-to-air missiles.

Atomic bombers could carry out high-altitude bombing missions at supersonic speeds without having to refuel. These bombers could also perform low-level bombing missions very efficiently.

Atomic planes would also be effective in launching intercontinental missiles.

Some designers believe that atomic planes could be developed to monster size with seven times the weight of the largest present-day passenger transports. In that event, they could carry large numbers of troops and military equipment.

It is anticipated that atomic planes will be serviced by a ground contraption nicknamed the "Beetle." It will contain 75,000 pounds of lead and steel shielding for protection against radiation. Its mechanical



This self-propelled "Beetle" has been designed for making adjustments and repairs in atomic power plants and atomic planes. The operator of the "Beetle" is shielded from radiation by 37 tons of lead and steel.

arms, 16 feet long, will be attached to a cab that can be raised 15 feet and rotated 360 degrees. Each "hand" will have an electrical outlet to manipulate power tools. The Beetle will have "eyes" consisting of glass windows 22 inches thick.

Moving on rubber tires, it will be powered by a 750-horsepower engine and its wheels will be driven and controlled independently.

THE HYDROGEN BOMB

Destructive as the atom bomb is, there is a limit to its size, which is determined by the critical mass at which it will explode. In the case of the hydrogen bomb, this kind of limitation does not apply; the bomb can be made bigger and bigger — hence more and more destructive.

The atom bomb is a fission bomb — tremendous energies are released by splitting of atoms. The hydrogen bomb is a fusion bomb — even greater energies are released by forcing atoms together.

Hydrogen is the favored ingredient because in the fusion process

lighter atoms release greater amounts of energy. However, the common form of hydrogen is not suitable for use in the bomb. In order to obtain the speedy reaction required, it is necessary to use hydrogen isotopes — deuterium, or tritium, or a combination of both. The last form is the most powerful of all. As in the sun, the hydrogen atoms fuse to form helium and liberate enormous amounts of energy.

To bring about fusion, fantastic temperatures have to be produced — on the order of 50 million degrees Centigrade. This is a great deal hotter than the interior of the sun. The only way to create such a temperature is to use an A-bomb explosion to "trigger" an H-bomb explosion.

HARNESSING FUSION FOR PEACE

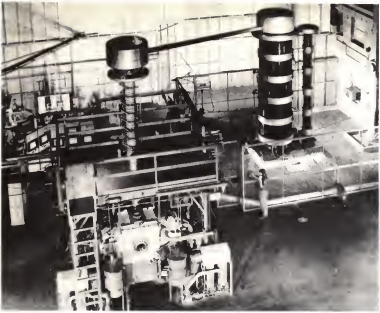
When it was first suggested that the most destructive force in the world could be applied to peacetime uses, the idea seemed nonsensical. Yet, if this were practical, it would confer the greatest benefits on mankind.

To begin with, fusion could supply man's power needs for at least a billion years. The smallest thermonuclear reactor that could be built according to present-day knowledge could give enough heat to produce five times as much electricity as was used in the United States in 1954.

The actual mechanics of the process have undeniable attractions. There would be no radioactive wastes. As no neutrons are involved, there is no need for a moderator. Finally, it seems likely that electricity can be produced directly, doing away with the whole steam-turbine-generator cycle and all the equipment and designing problems involved.

Even the matter of atomic "fuel" is simplified. To obtain pure uranium is a costly, complicated and time-consuming process. Tritium, to be sure, is much rarer and can only be produced in the laboratory. Deuterium, however, can be extracted easily and plentifully from sea water. "By far the greatest reserve of stored energy," it has been said, "is locked in the nuclei in hydrogen atoms present in the ocean."

Yet the practical difficulties are so formidable that even the greatest scientists might well turn away in despair. Temperatures of 50 million degrees Centigrade are needed to fuse the deuterium atoms. The highest temperature that any containing-vessel material can stand is 6,000 degrees. (The Russians gave the whole problem a new twist when they announced early in 1957 that they had succeeded in fusing hydrogen atoms to produce helium by the use of excessively *low* temperatures. No details of this process have been revealed. However, on the use of low temperatures, see the description of the Alvarez experiment on page 193.)



The DCX thermonuclear experimental machine at Oak Ridge uses a cascade accelerator tube (center) and a connecting high-voltage generator (right). The DCX is considered one of the most promising approaches to the fusion problem.

FUSION RESEARCH

Interestingly enough, though the problems seem staggering, several groups of scientists, all working independently of each other, have hit on the same basic theoretical approach to a solution.

In 1957 the Atomic Energy Commission announced that it was planning to construct a large experimental device for producing controlled thermonuclear reactions. The equipment, located at the Forrestal Research Center at Princeton University, is called a "Stellarator." It is a model of a star like the sun, imitating the processes that go on in the sun at very high temperatures.

Since any known containing-vessel material would be vaporized by the fusion process, it is necessary to use what scientists call a "magnetic bottle," in which magnetic lines of force acting at a distance would force the deuterium gas into a very narrow beam. To accomplish this it would be necessary to electrify the gas first by means of well-known techniques.

The gas, controlled by the magnetic field, can thus be raised to very high temperatures after being forced to travel in spirals without ever approaching the walls of a container. Basically, the Stellarator is a hollow tube in which the electrified gas is confined. The tube is surrounded by coils which create the desired magnetic effect. It is hoped that after the electrified gas has been heated to the required temperature, it can remain confined long enough to enable fusion to take place.

At Los Alamos, scientists are working on several fusion machines. One is the hopefully named "Perhapsatron," which has reached temperatures of 6 million degrees. A second machine, the Columbus S–4, uses a vertical glass tube and operates with liquid nitrogen at –273 degrees to combat overheating. The third, the Columbus II, also uses a vertical glass tube and a million-ampere current to reach temperatures of 5 million degrees.

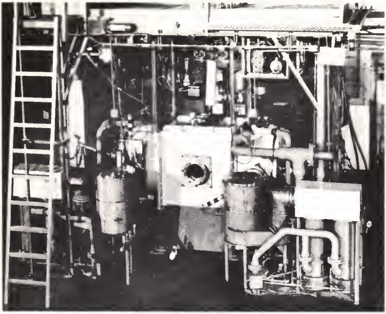
The fourth machine, Scylla, is the most promising of all; it is believed to have carried out successful fusion by attaining temperatures close to those in the sun. Under temperatures of about 10 million degrees, about 20 billion neutrons stream out of the "pinched" gas in a millionth of a second. While there is strong evidence for believing that fusion occurred, no definite claim for fusion is being made at Los Alamos until conclusive tests have been made.

Similarly, the DCX thermonuclear machine at Oak Ridge Laboratory is believed to be on the verge of achieving fusion. Here too, a definite judgment must wait on the construction and testing of an improved version of DCX — which will not be possible until some time in 1960.

At the University of California's Radiation Laboratory, which is directed by Edward Teller, "father" of the hydrogen bomb, fusion possibilities are being studied on several levels. Project Ploughshare involves research on constructive uses of the fusion reaction. The thermonuclear device called the "Astron" ("star"-machine) is a wholly novel approach to fusion: it dispenses with magnets and utilizes a layer of electrons to provide the magnetic "pinching" force and to heat the deuterium gas as well.

The Russian thermonuclear machine, "Ogra," operates on more orthodox principles, and is unusual only in its enormous size.

Judging from reports issued by British scientists in 1957, they are also making great progress. These reports offer mathematical equations to show that temperatures exceeding those in the interior of the sun can be produced experimentally and maintained long enough for fusion to take place. The British program for achieving fusion has been systematically divided into six stages. The first of these, liberating an



Another part view of the DCX thermonuclear experimental machine at Oak Ridge. The window in the center permits direct observation of some of the complicated processes that are involved.

infinitesimal amount of energy, has been completed. At temperatures of 5 million degrees, the energy output has amounted to about one-trillionth of the energy used to produce the reaction.

The second stage will involve verifying that the neutrons of the newly formed atoms come from the thermonuclear reaction and not from some by-product reaction inside the fusion chamber.

In the third stage, temperatures will be raised to 25 million degrees.

The fourth stage will reach the break-even point between energy input and energy output. By that time research will be able to show how output can begin to exceed the energy expended.

In the fifth stage a working prototype of a practical and economical thermonuclear station will be constructed.

The sixth and final stage will be the commercial application of the process to generate electrical power.

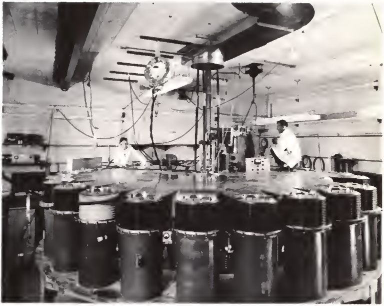
Zeta, the British fusion reactor, is a doughnut-shaped tube. A magnetic field "squeezes" or "pinches" the gas into the center of the tube.

By producing heat at brief intervals, high temperatures may be reached in brief electrical pulses and then lowered in the gap between pulses. (The same principle is used in the automobile engine: the explosions in a gasoline engine are pulsed in this way and thus become feasible despite the fact that temperatures of the individual explosions are well above the melting point of the cylinder.)

The temperature of the fusion process is estimated by including oxygen in the gas and then measuring the spread of the oxygen light band on a spectrograph. The greater the heat, the broader the band.

Dr. Luis Walter Alvarez has discovered a third method of producing atomic energy which is altogether different from the fission and thermonuclear processes. He used negative mu-mesons as catalysts to make hydrogen nuclei fuse with deuterium nuclei. What is particularly interesting about this reaction is that it takes place at low temperatures.

The fusion produces helium 3 (an isotope) and releases an enormous amount of energy — about 5,400,000 electron volts for each



The Columbus II is one of the thermonuclear experimental machines at the Los Alamos Scientific Laboratory in New Mexico. It has been designed to obtain the maximum amount of current in the shortest possible time. Shown here is a partial view of some of the condensers used.

reaction. The mu-meson does not get used up in a single reaction, but since it has a life of only a millionth of a second, it can repeat the reaction only once or twice.

This form of fusion, which is quite infrequent, can be studied in a bubble chamber. It appeared 15 times in 75,000 bubble-chamber photos. Commenting on the discovery, Dr. Alvarez stated: "If this is to become of practical importance, we would have to find a different catalyzing particle which has properties similar to the mu-meson but has a lifetime of at least 10 or 20 minutes." And he added, "It is interesting that Russian scientists have reported evidence that such a particle does exist in cosmic rays." If such energy-producing reactions could be put on a practical basis, they would presumably be able to produce enough energy to operate electrical generators.

FALLOUT RADIATION DANGERS

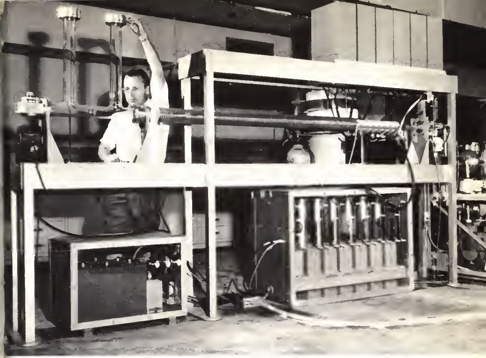
Every explosion of an atomic or hydrogen bomb results in substantial amounts of radiation which circulate in the atmosphere and are gradually spread all over the world. Just how much radiation is produced, and how harmful it is, have been the subjects of conflicting claims by equally eminent scientists. Baffled and frustrated by the clamor, the layman has become more and more alarmed.

A dose of 100 roentgens (unit of measurement for radiation) at one time would do serious damage. A dose of 500 or more roentgens is likely to be fatal. Less than ½ roentgen a week is considered the maximum for safety. But the problem is complicated by the views of some scientists who hold that even tiny amounts can add up to a cumulative effect that could be harmful.

Judging from the symptoms observed in radiation victims and other evidence, it is believed that radiation destroys the cell nuclei; breaks down proteins; and ionizes (charges) the hydrogen atoms in the tissues. These hydrogen atoms, so the theory runs, attract oxygen from vital enzymes which have the function of supplying energy to body cells. With the enzymes unable to carry on their work, the cells die from lack of nourishment.

The most dreaded effect of radiation is leukemia, which is characterized by an abnormal increase in the number of white blood cells. The amount of increase may be more than 25 times normal. The result is that the abnormal cells squeeze out the other cells that are essential to the living process, with fatal consequences for the victim.

Radiation is particularly dangerous for the bone marrow cells. Strontium 90, one of the ingredients of bomb fallout, has a comparatively long half-life and the role of its dangerous gamma radiation in

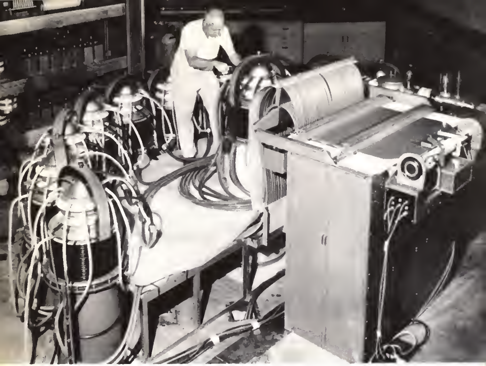


The Plasma Acceleration Machine (P.A.M.) at the Los Alamos Scientific Laboratory is an almost streamlined version of the experimental fusion process. When a gas is admitted at the right, it is ionized by a shock coil, accelerated down the tube, and then strikes the ballistic pendulum, making it move.

causing leukemia has been hotly disputed. Strontium has a natural affinity for the bone-marrow cells, which produce 85 per cent of the blood cells. These cells live for only a few days and under normal conditions are regularly replaced. But radiation prevents the forming of replacement cells.

According to studies at Columbia University, the amount of strontium 90 in human bodies has increased by a third since bomb tests began. In children under four, the increase was double the average. But this was 1/150th of the allowable maximum. Continuation of the tests would increase the concentration of strontium, unless "clean" bombs are developed to reduce the amount of strontium in fallout.

The increase of strontium among young children, who consume a great deal of milk, points to the most worrisome danger anticipated from growing concentrations of strontium 90. As this substance has a half-life of some 28 years, it is feared that it will be deposited on fields



This thermonuclear experimental machine ("Scylla") at the Los Alamos Scientific Laboratory is believed to have carried out successful fusion by attaining temperatures close to those in the sun.

and then consumed by grazing animals, eventually finding its way into our milk supply.

A subsequent analysis by the United Nations Committee on the Effects of Radiation was even more pessimistic. It concluded that as a result of bomb tests, about 2,000 persons contracted leukemia annually and that "even the smallest amounts of radiation are likely to cause deleterious somatic effects."

On the other hand, the conclusion from recent experiments at the Argonne National Laboratory is that "the present contamination with strontium 90 from fallout is so very much lower than any danger levels that it is extremely unlikely to induce a single bone tumor or one case of leukemia." In this case, the lowest amount of strontium 90 which led to a noticeable shortening of the life of laboratory animals was 3,500 times greater than the maximum permissable level set for man.

Another possible consequence of radiation is its effect on the reproductive organs, leading to sterility or else causing mutation effects that would increase the number of malformed births. In the latter case, the results could be recessive, and make their effects felt years later.

Public alarm over these possibilities has been heightened by announcements from time to time that seemingly harmless sources of radiation have become suspect. Recent research on certain kinds of watches with luminous dials is a case in point.

These dials, the research report concluded, emit more radiation in five years than the full safety quota for anyone up to the age of 30. "When one further considers," the report points out, "that this radiation is several times greater than natural background radiation and exceeds by more than one hundred times that presently received from radioactive fallout, the potential hazard to the wearer of a luminous-dial wrist watch raises the question as to whether the small benefit that may be received from such a watch is worth the hazard."

RADIOACTIVE WASTES

The problem of fallout is further intensified by the growing dilemma created by the piling up of radioactive wastes from nuclear reactors. The electrical power output of U. S. nuclear plants is expected to increase from 5 million kilowatts in 1965 to 175 million in 1980. It is estimated that by 1965 the annual amount of radioactive waste products will equal the amount of radiation released by 3,000 tons of radium. By 1980 the waste radiation will have increased thirty-fold.

Nuclear scientists have lavished great ingenuity on reactor designs that will diminish the amount of radioactive waste. They have used every possible precaution for making the reactors safe and not subject to human error. They have devised clever ways of turning some radioactive wastes to good use. Safe disposal methods have been their constant goal. Yet the problem continues to grow.

Dr. Bentley Glass, a leading American biologist and geneticist, has asked, "Can we depend on storage underground with possible contamination of soil and water supplies?" And he adds:

"The Los Alamos Laboratory alone has already used up 40 acres of underground storage and needs a new site for that purpose. Or can we envisage storage in ocean depths, with the possibility of overturn of even stable waters sufficient to contaminate marine plant and animal life, and thus eventually all of the lands adjoining the sea? The very bulk of these long-lived fission products will be so enormous that containment within corrosion-proof vessels, even for 30 to 50 years, will be virtually impossible."

SOME COUNTER-MEASURES

But there are hopeful developments too. One is in the field of developing instruments that will be more sensitive to radiation than our present methods. There is, for example, a new and ingenious pin-hole camera which detects sources of radiation too small in quantity to be picked up by a radiation counter. The camera can also be used to locate contamination in areas that are too "hot" for using orthodox detection instruments. It has the additional virtue of being able to photograph contaminated objects that would fog the film in an ordinary camera.

The radiation camera has the shape of an old-fashioned box camera and is about the same size. But its lens barrel is made of uranium and it weighs 29 pounds because of its lead housing.

Another unusual feature of the radiation camera is that it uses two sets of film — one is conventional and the other is X-ray film. After both films have been developed, the X-ray film is superimposed on the plain film to show the location of the radiation sources.

Important developments are taking place in the field of radiation medicine — the study of how radiation affects living creatures and what methods can be used to combat these effects.

At Oak Ridge Laboratory a good deal of research has been devoted to a drug called "AET" — an abbreviation of a very long chemical

This pin-hole camera was designed at the Knolls Atomic Power Laboratory to be used in locating contamination in areas of high-level radioactivity. The camera's lead housing prevents the entry of radiation at any other point than the aluminum window.

compound — to reduce the harmful effects of radiation. Numerous tests on laboratory animals have indicated that a one-gram pill of the drug could halve the extensive radiation damage to an average person's blood and blood-forming system. AET, which apparently localizes in the bone marrow, is still undergoing tests for toxicity.

For the drug to take effect, it must be administered before the radiation damage takes place. The most effective time seems to be less than an hour in advance. While it is true that this greatly diminishes the practical value of AET, the compound is of considerable experimental value in pointing the way to more effective drugs.

Tests at the Yale Medical School seem to indicate that yeast extract is an excellent specific against the effects of radiation. It is thought that its effectiveness is due to its RNA (ribonucleic acid) content, which is a component of all living cells.

In the Yale experiments, 42 mice and rats were injected with the yeast. Then these rodents, together with 155 other rodents which had received no injections, were given doses of 700 to 900 roentgens of radiation. Thirty days after this fatal dose, all 155 rodents who had not been given the yeast were dead. Of those who had received the extract, 27 died while 15 survived in good health.

Yet the great danger remains, succinctly summed up in these words of Professor George W. Beadle, one of the world's great geneticists: "I am prepared to say that fallout is biologically harmful and that we must therefore recognize a moral responsibility to humanity to reduce it to the lowest possible level."

In accordance with this thought, an international congress of scientists from the United States, the Soviet Union, Great Britain and five other countries, tentatively agreed in August 1958 on an inspection system to police a ban on nuclear weapons tests. The delegates calculated that about 180 listening posts would be required for carrying out the plan.

Basically, there are four ways of detecting such explosions:

(1) Sensitive micro-barometers record the sound waves generated by explosions. This is the favored method for detecting above-surface explosions.

(2) Radiological debris which accumulates in the atmosphere from an atomic explosion is collected. This is less valuable for initial detection than for assembling evidence that an atomic explosion has occurred.

(3) Seismographic equipment records the earth shock waves that are produced by atomic explosions underground or near the surface.

(4) Electromagnetic radiation (in the form of radio waves and

A scientist attaches a voltage measuring device to the "Perhapsatron," one of the experimental thermonuclear machines at the Los Alamos Scientific Laboratory.

visible light) given off by above-surface atomic explosions is recorded.

Thus mankind has the means at hand for protecting itself against possible disaster from atomic bomb tests. The human race has now reached the stage foreseen by Francis Bacon four hundred years ago, for it holds the key to "the knowledge of Causes, and Secrett Motions of Things; and the Enlarging of all Things possible." Whether that knowledge will be used for good or ill is perhaps the greatest problem of our times.

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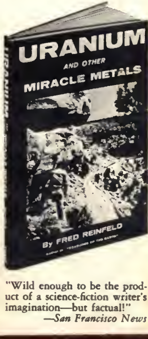

"Wild enough to be the product of a science-fiction writer's imagination—but factual!"
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